Experimental Investigation of performance of 400 kV line Insulators under pollution

by

Manoj Rai

DEPARTMENT OF ELECTRICAL ENGINEERING

Indian Institute of Technology Kanpur

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Experimental Investigation of performance of 400 kV line Insulators under pollution

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Manoj Rai

DEPARTMENT OF ELECTRICAL ENGINEERING
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Certificate

It is certified that the work contained in this thesis entitled **"Experimental Investigation of Performance of 400 kV line Insulators under Pollution"** by **Manoj Rai** has been carried out under my supervision and this work has not been submitted elsewhere for a degree

Dr. Ravindra Arora
Professor
Department of Electrical Engineering
Indian Institute of Technology
Kanpur-208016, India

January, 2003

Dedicated to my

Beloved Parents

Acknowledgement

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Last but not the least, I thank God for His constant inspiration.

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Abstract

In many parts of the world, Insulator contamination has become major impediment to the uninterrupted supply of electrical power. Outdoor insulators are subjected to nature Polluted environmental contaminants, which may include sea salt, cement dust, fly ash, birds droppings, industrial emissions etc. deposit on their surface With the increasing industrialisation not only the degree of pollution but also the type of pollution has an effect on the performance of the insulators

In the present work, Experimental investigation of the Performance of 400 kV line ceramic insulators under Pollution is studied. Flashover under dense fog conditions on 400 kV Kanpur-Obra line has been investigated. For these investigations four single ceramic insulator discs of the actual line were made available. Two out of which was used one and other two were unused (new). One each old and new was of 160kN and other two were of 120kN mechanical strength ratings. Different failure modes of the Insulators were investigated. Pollutant Layer on the insulator was analysed using X-ray Diffraction meter. It showed that the Pollutant dust layer on insulators contained a large percentage of Nacl, KOH, and $Caso_4.2h_2o$. Flashover tests under different simulated atmospheric conditions were performed. Experimental results revealed that under Polluted and wet conditions, the flashover voltage falls below 10 kV whereas it was measured to be more than 60 kV under Polluted and dry conditions. Experimental results did not have significant difference for old and new insulators. Capacitance's of old and new insulators were measured with the help of Schering Bridge Surface gradient estimation on the three Phases of the line has been made. The voltage distribution across the insulator string has also been estimated. Remedies are suggested for reducing flashover on polluted lines. Literature study revealed non – ceramic insulators are more effective under polluted conditions. Particularly RTV Silicone coated ceramic insulators have been found very effective under polluted conditions.

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Introduction

1.1 Introduction

Reliable generation and distribution of electrical power is becoming more and more important in terms of macroeconomics, as worlds industrial growth expands, particularly in developing nations. Consistency in transmission and distribution of power is crucial to continued economic growth. Ironically, industrialization leads to increased level of environmental pollution and air borne contaminants that can in turn trigger interruptions in power supply and delivery caused by insulator based leakage current induced flashover outages.

Transmission and distribution of electrical energy can also be affected by salt fog conditions that occur in coastal areas. Given that a large percentage of the world's economic activity is located in close proximity to the sea, salt fog contamination is a major concern for electrical industry as a whole.

Industrial airborne pollutants, dust caused by arid and weather conditions and salt fog contaminants get readily deposited on high voltage insulators. They generate phenomena enhancing the leakage current. Rainfall and conditions of high humidity and most severely the fog exacerbate leakage current levels to the point at which flashovers are created. Under certain conditions, currently quite prevalent in regions experiencing heavy pollution, leakage current itself becomes a significant power waste factor. Power loss due to leakage current becomes significant under such conditions. The extent of this waste of revenue has not been quantified. However, as unit costs of power generation become more competitive, the direct bearing that these cost have on the economical well being of the country.

more competitive, the direct bearing that these cost have on the economical well being of the country.

In addition to the ongoing lost of revenue, a more severe aspect of the development of leakage currents on insulators is the occurrence of flashover. This happens quite often when the leakage current levels are excessive and the atmospheric conditions conducive to flashover are present Such conditions include heavy smog and high humidity in combination with mist or light rainfall. Flashovers are very damaging as they not only affect the utility's revenue and repair cost but more importantly, their customers are inconvenienced by the ensuing power outage. In the case of industrial customers, a loss of power leads to manufacturing interruptions and in some cases products can be seriously damaged This is particularly true of the computer components and electronics industry, where strict manufacturing processes and environment cannot be seriously compromised by unexpected power failures.

An obvious answer to the problem of power outages would be to provide sufficient standby generation capacity with the ability to divert this backup spinning supply through a grid network automatically & instantly. Of course its clear that how cost prohibitive such a simple solution would become. Decades ago when energy costs were low and economies strong, both North America and Europe followed this practice to a large extent. Today this is no longer a viable solution, particularly for the developing nations of the world. On the face of it, the idea of a large grid supplied with excess generating capacity would appear to be very reliable.

The electrical power industry constantly strives and continues to strive to develop a cost effective solution to the problem of contamination related leakage current power losses and the accompanying outages In fact, under serious contemplation presently is the policy of complete avoidance of centralised power generation and long distance transmission. In its place a decentralised approach of small localised generating units using wind power, natural gas, fuel cells, etc. for each household, and also for large

facilities for industries. This concept is still a long way from becoming a real alternative to central power generation and transmission grids.

There has been a great deal of work on improvement of high voltage insulators performance. The insulator industry has achieved significant advancements. A major contribution has been to make the insulator surface with a high degree of sustained hydrophobicity Ceramic insulators have been provided with a better glaze, glass insulators demonstrated a better hydrophobicity, and various composite and polymeric design were developed to achieve this characteristic.

In this thesis chapter 2 describes various types of insulators, failure modes and terminology associated with insulators Chapter 3 discusses pollution, fault causing pollutant and different types of pollution levels. Chapter 4 is on Physics of contamination. This chapter discusses electrically significant deposits, different contamination processes and purging processes. Chapter 5 describes physics of pollution flashover. It discusses different stages of the flashover process. In chapter 6, 400 kV Kanpur – Obra transmission line flashover problem is taken up. It includes chemical analysis of pollutants and procedure for experimental work in lab. Chapter 7 is on experimental setup giving details of the instruments used are listed here. Chapter 8 is on results and discussion. Chapter 9 discusses composite insulators under polluted conditions. It also describes Benefits of silicone rubber, phenomena of hydrophobicity and experience of different countries with composite insulators. Chapter 10 describes remedies for insulator flashover. Conclusions and scope for future work are discussed in chapter 11.

Chapter 2

Insulator

The principal dielectric used on overhead power lines is air at atmospheric pressure. The air, surrounding the bare high voltage aluminium or steel cored aluminium (ACSR) conductors, is a good insulating material, provided that the electric stress is kept below the ionisation threshold. It is, however, necessary to attach the conductors at certain points onto the cross arms of pylons The problem of reliably suspending the conductors of high voltage transmission lines has therefore been with us since the turn of the century. The task is particularly complex, bearing in mind the multiple extreme stresses present: mechanical, electrical, environmental

High voltage insulators have developed rapidly since early this century beginning with simple porcelain insulators. Today, modern polymeric insulators are used, as well as early materials. A classification of the main types of insulators is shown schematically in figure 2.1.

2.1 Types of insulators

Porcelain pin type insulators

These were originally used for telephone lines and lightning conductors, have been adapted for power transmission and some variations are still in use for medium voltage system.

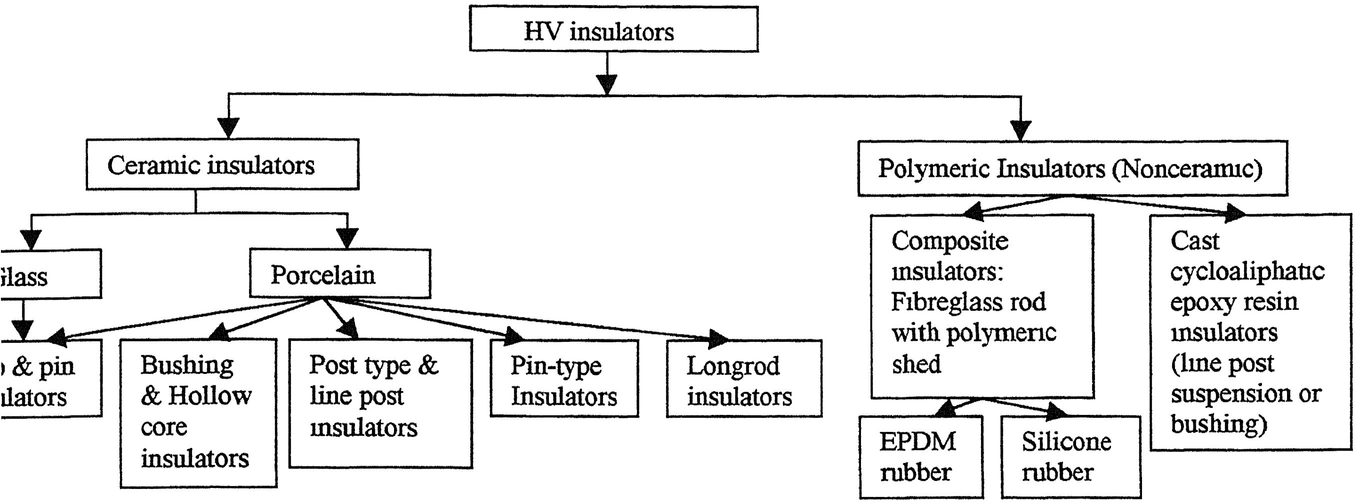


Fig 2.1 The classification of power line insulators

Cap and pin type insulators

These are manufactured from porcelain or glass and are based on same principles as pin-type insulators A number of units are connected together by steel caps and pins to form an insulator string. These strings are used for suspension and tension insulator. The caps and pins are fixed to glass and porcelain disc with cement. The conical shapes of the fitting ensure high mechanical strength under tensile stress. Typically an insulator string can handle loads of up to120kN i.e. 12 tons. Pin type and cap and pin insulators are classified as class B insulators; the shortest distance between the metal electrode through the porcelain or glass is less than 50% of the shortest distance through the electrodes. The porcelain or glass can therefore be punctured by severe electrical stress. The manufacturing process of glass insulators includes thermal cooling that ensures that the glass sheds shatters in the event of puncture. A faulty disc is therefore clearly visible. The mechanical integrity of the insulator remains intact.

Post-type and line post insulators

These insulators consist of a solid porcelain cylinder, corrugated to increase creepage length, with metal ware on each end. They are used to support high voltage conductor and are mounted on pedestals or on the power line cross arms. Post insulators are tall and are mainly used in substations. These insulators are class A; the shortest distance through the porcelain exceeds 50% of the shortest distance through air between the electrodes. They are therefore unpuncturable.

Porcelain longrod insulators

Longrod insulators are similar to post insulators but are lighter, slimmer and are used as suspension insulators. Longrod insulators have the apparent advantage over cap and pin insulators in that metal fittings exist only at the ends of insulators.

Bushing

Bushings are used to insulate the conductors of high voltage terminals of a transformer. Traditionally, transformer bushings are manufactured using porcelain. Capacitive grading, using foil cylinders is often used to improve the axial and radial field distribution.

Composite polymeric insulators

These insulators are similar to longrod insulators but consist of:

- A glass fibre reinforced resin core to provide the mechanical strength, while resisting the electrical stress.

- Elastomer sheds to provide the required creepage and stress reduction to withstand the stresses prevailing on the system Two commonly used materials are silicon rubber and EPDM (ethylene propylene diene monomer) rubber.

In these insulators the metal end fittings are usually crimped onto the glass fibre rod from the environment and the interfaces between the elastomer and the metal fittings are very important.

A major advantage of composite polymeric insulators is an up to 90% weight reduction when compared to ceramic equivalents. They are also reasonably vandal-proof.

Cyclo-aliphatic epoxy resin insulators

Cyclo-aliphatic resin can be used to cast insulators similar to porcelain and linepost insulators for distribution voltages. In severe environments the surface of the insulators become rough- a factor that may affect the reliability of insulators, when incorrectly applied

2.2 Functions of insulators

All insulators have dual functions, mechanical and electrical, which present conflicting demands to designers. The most serious conflicting factor is the impossibility, in practice of providing an ideally nonconductive element. All insulators have external surfaces, which will become contaminated, to some extent in service. The contamination will carry leakage current, the surface layer, on a typically polluted insulator, will contain inert mineral matter, electronic conducting dust like carbon or metal oxides, soluble salts and water. This layer will behave as a highly variable and non-linear resistor in most cases unstable in the presence of electric fields. The leakage currents, which it carries, give rise to heat, electrochemical products of electrolysis and electrical discharges. Secondary consequences will range from electrochemical erosion through discharge ablation to complete by passing of the electrical insulator by flashover.

Recently, the insulator pollution problem is receiving considerable attention with the development and uprating of power transmission systems and reduction of design insulation level Therefore, problem of designing insulators to withstand contamination has become an important design consideration of HV transmission systems in industrial regions desert sites and coastal areas. The flashover voltage of contaminated insulator depends on the kind and quantity of contaminant along with ambient temperature, pressure and humidity Therefore both chemical analysis of the pollutants and measurement of severity of pollution is necessary from design and maintenance point of view.

2.3 Failures modes of insulators

Flashovers, caused by air breakdown or pollution, generally do not cause physical damage to the insulators and the systems can often be resorted by means of autoclosing. Some others events, however, cause irreparable damage to the insulators

Puncture

As previously mentioned, porcelain pin-type and cap and pin insulators may suffer punctures between the pin and the either the pin or high voltage conductor. These occurrences are usually caused by very steep impulse voltages, where the time delay for the air flashover exceeds that of puncture of porcelain.

Punctures caused by severe stress over dry bands also occur on composite insulators on sheds and through the sheath. A puncture of the sheath is particularly serious as this exposes the glass fibre rod to the environment

Shattering

Glass insulators shatter when exposed to severe arcing or puncture due to vandalism. One advantage is that they retain their mechanical integrity.

Erosion

Prolonged surface discharge on the glass insulators leads to erosion of the surface layer of the glass. This may lead to shattering of the glass discs – a result of the tempering process used during manufacture. Surface discharge over long periods may cause removal of shed or sheath material in the case of polymeric insulators Severe erosion may lead to the exposure of the glass fibre core

Trackıng

Tracking or surface discharge occurs when carbonised tracks form because of polluted surface condition. These tracks form conductive path.

Water entry into the glass fibre core of composite insulators, coupled with the influence of weak acids, has been shown to lead to brittle fracture of the rod The by-product of partial discharges in the presence of water can lead to the formation of weak acids. The integrity of the metal/polymer and glass/polymer interface is therefore extremely important – especially if acid resistant glass is not used.

Corrosion

The corrosion of metal fittings clearly affects the mechanical performance lifetime of insulators. The corrosion products, running onto the insulator sheds can also deterioration.

Partial discharge at cementing portion

The metal cap is cemented with every disc insulator. At this joint, voids are formed which are highly vulnerable to Partial Breakdown during service.

2.4 Terminology

When applying insulators, it is necessary to describe the insulator dimensions, using the following terms

- Creepage distance: the shortest distance between the metal ware at two ends of the insulator, when following the contours of the insulator, excluding intermediate metal fittings. This distance is easily measured by sticking masking tape to the insulator surface.
- Specific creepage distance: The quotient of the creepage distance in mm and the line to line rms voltage of the three phase system in kV
- Connecting length· the distance between the metalware, measured as the length of a tightly pulled piece of string
- Intershed spacing: the distance between corresponding points on adjacent sheds.

Chapter 3

Pollution

Atmospheric pollution leads to deposition of pollutants and chemicals on the surface of insulators of overhead lines. In some areas insulators are more prone to failure than in the other areas also insulation failure depends on the nature of pollutant.

3.1 Sources of pollution layer deposition

Insulators exposed to environment collect pollutants from various sources. Pollutants that become conducting when moistened are of particular concern. Two major sources are considered:

- Coastal pollution: the salt spray from the sea or wind driven salt laden solid material such as sand collects on insulator surface. These layers become conducting during period of high humidity and fog. Sodium chloride is the main constituent of this type of pollution.
- Industrial pollution: substation and power lines near industrial complexes are subjected to the stack emissions from the nearby plants. These materials are usually dry when deposited; they may then become conducting when wetted The materials will absorb moisture to different degrees, and apart from salts, acids are also deposited on the insulator.

  The cause for dielectric puncture of the insulators of transmission line has been traced due to the presence of a phosphatic rock crushing/milling unit in the close vicinity of line towers. After milling the phosphatic rock become very fine dust that gets carried by the winds sweeping the area. The phospharite dust gets mixed with the other dust particles. The atmosphere around the conductor insulator is thus laden with dust having ionic constituent and on account of electrostatic stress resulting from very

high voltage; these charged particles impinge on the conductor and get glued to the insulator surface and also with each other. This leads to the formation of Electro sediments which under suitable condition of humidity and ambient temperature leads to the dielectric failure of insulators.

Analysis of pollutant samples from the failed insulators indicate that silica, alumina and lime were the major constituents while iron oxide, magnesia, phosphate and sulphate and sulphate residue were found in relative small amounts. The crust due to this pollutant on insulator surface was found to have crystalline nature also the nature of sample was not entirely acidic or base.

- A number of insulator failures have also been reported on lines passing near to the cement plants and stone crushers. In this also huge quantity of lime stone dust particulate get deposited over the insulator surface, on absorption of water by the particulate layer and under the influence of high voltage field, electric discharges take place through the film of pollutant. Similar problems have been reported on lines passing near to coal stockyards.

  Chemical pollutants containing sulphur dioxide, hydrogen sulphide and nitrogen oxide has also been found to cause of failure.

Besides these there are pollutants from other sources, which can also result in flashover such as:

- In urban area exhaust from vehicular traffic, smoke, and dust are the major pollutants. The carbonaceous matter with traces of lead which are generated due to huge vehicular traffic get collected in the form of layer on the surface of insulators of nearby transmission line.

  This pollutant has soot like behavior when the dust particles settle over the layer, the conductance of layer increases in the presence of moisture or water. This leads to reduction in the creepage distance of the insulators also dry bands are formed.
- Insulators of line towers passing near by the sites where land filling is done by garbage are found to be polluted by bird excreta, during mild rains the surface of insulator form a conducting film. The creepage distance of insulator is thus reduced.

3.2 Levels of pollution

Pollution Level	Example of typical environments
I – Light	Areas without industries and with low density of Houses equipped with heating plants, Area with low density of industries or houses but subjected to frequent winds and/or rainfall; Agriculture areas, Mountainous areas; and All these areas shall be situated at least 10 km to 20 km from the sea and shall not be exposed to winds directly from the sea.
II – Medium	Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants; Areas with high density of houses and or industries but subjected to frequent winds and or rainfall; and Areas exposed to wind from the sea but not too close to the Coast (at least several kilometers distant).
III – Heavy	Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution; and Areas close to the sea or in any case exposed to relatively strong winds from the sea.

IV- Very heavy	Areas generally of moderate extent subjected to conductive dusts and to industrial smoke particularly thick conductive deposits; Areas generally of moderate extent, very close to the coast and exposed to sea – spray or to very strong and polluting winds from the sea, and Desert areas, characterized by no rain for long period, exposed to strong winds carrying sand and salt, and and subjected to regular condensation

Chapter 4

Physics of contamination

4.1 Electrically significant deposits

The terms contamination and pollution have special meaning when applied to conditions of insulators. An insulator so heavily polluted by marine deposits that it flashes over immediately on energisation may appear to be perfectly clean, even on close inspection. On the other hand, one which is black with industrial soot, or one with some of its surfaces caked with cement may have an electrical performance indistinguishable from that of a freshly installed counterpart.

The reason for this apparent paradox is that value of surface electrical conductivity, which is sufficient to cause flashover, is quite trifling in absolute terms. They are readily achieved by the presence of soluble electrolytes, such as, common salts or industrial acids, at densities of some 0.1mg/cm^3, provided water is available to dissolve them. Layers of carbon particles, which make only intermittent point contacts with each other, do not readily achieve them, or by aggregate of mineral dusts, which are free of ionic components.

The deposits which are of greatest significance, in the performance of insulators, are therefore highly soluble electrolytes originating for example, from the sea, from road-salt, from salt-flats and desert dusts, and from industries such as petrochemical and other acid generators; less dangerous, although locally important, are the above mentioned aggregates, fly-ash from generating plants which burn pulverised coal, and industrial fumes. Both the soluble ionic and inert layers require water before they can act: fog, dew and drizzle are hence highly significant deposits.

Pollutants, which remain electrically conductive even in the absence of water, include carbon, some metallic oxides and metals in the form of dust or powders Flashovers directly caused by these are rare; However, In the case of railway insulators, oxides of iron may cause considerable contamination from the wheel brakes or by carbon or copper ablated from conductors or pantographs. Such contamination may be reactive with polymeric insulators and with insulator greases, and have caused severe damage in association with other pollutants

A very fine silica dust used in the manufacture of some protective silicon pastes, which are applied to insulators. Destruction of this silicone, by discharge and weathering, allows the silica to adsorb water in such quantities as to cause local damage by joule heating.

4.2 Contaminating processes

The principal processes which transport material on the surface of insulators are gravitational forces, electrostatic attraction of electrically charged particles, dielectrophoretic migration of high-permittivity particles into regions of high electric field, evaporation of solutions or suspensions and aerodynamic catch. The last is entirely predominant in importance.

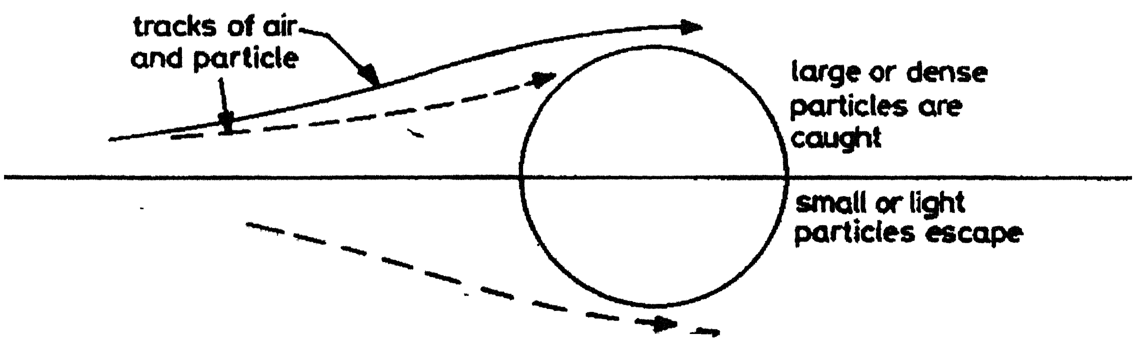


Fig. 4.1 *dependence of catch on nature of particle*

Particles of small radius or density are held in the diverted flow by viscous forces

When air, containing suspended particles, flows towards an insulator the efficiency with which the insulator catches particles depends upon the shape of the insulator, the size and density of the particles and on the speed of the flow. The insulator forces the flow to divide, leaving a stagnation point where the air is at rest. The flow changes the direction away from the stagnation point, but the suspended particles, having densities greater than that of air, are unable to follow the flow accurately and pursue paths of lesser curvature this motion relative to the surrounding air is resisted by the viscous force on the particle, however it is small for low particle diameters and densities.

Once the deposits have significant thickness, they have the secondary effect of modifying the airflow, both by increasing the frictional drag and by causing subsidiary vortices. Heavily convoluted insulators may become clogged as a result of such cumulative catch, with disastrous effect on their electrical performance by the loss of effective creepage path.

The simplest case of particle catch is the deposition of relatively large, dense granules at a point of stagnation where there is no force to remove it. Much more common and important, however are the effects of rotating-flow or vortex generation, arising from the disturbance to the air flow introduced by the insulator. Vortices are produced at the sides of the insulator, which affect other insulator in its wake, and also within the underside structure of the insulator itself, especially at deep skirts or sheds. Rotating flow of this nature gives rise to cyclonic action: a given population of particles will be trapped in a rotating volume for many cycles, and the time for migration to the wall of the insulator, against the viscous forces, will be prolonged. Many quite small and low-density particles will, in this way, be deposited moreover, within the convolutions[3].

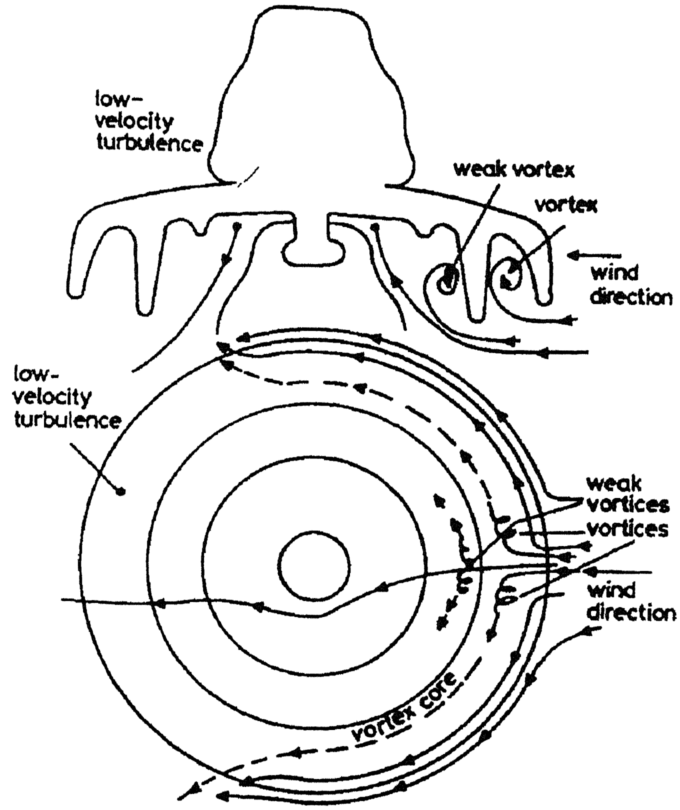


Fig. 4.2 *observe flow over antifog disc*

Smoke paths at 2.4m/s show vortices between skirts

The possibility of significant improvement in the performance of insulators could be achieved by modifying shapes, in the direction of lesser interference with incident airflow have been investigated. Studies in wind tunnel were made using two types of disc insulator and a dummy biconvex aerofoil. Flow patterns were measured, using paraffin smoke also titanic in oleic acid as a surface indicator. Actual deposits were quantatively compared, using talcum or suspension of magnesia as artificial pollutants, injected into flow upstream of the experimental pieces [3].

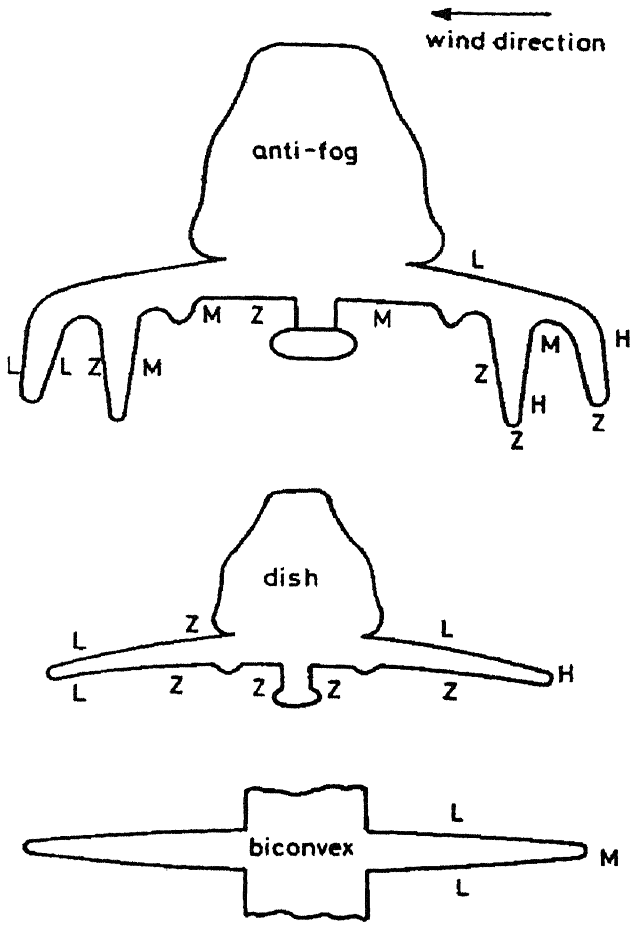


Fig. 4.3 *variation of pollution catch with shape*

H: heavy

M: medium

L: light

Z: zero deposit density

Catch of pollution on underside (mg)		
at 9m/s		at 1.5 m/s
630	anti-fog	150
390	dish	10
40	biconvex	negligible

The results (Fig. 4.3) showed that maintenance of high flow speed over the surfaces and elimination of vortices, especially those within the convolutions, had dramatic consequences for the catch of pollution. The quantities caught beneath the heavily convoluted discs were more than 10 times higher than for the biconvex shapes, but density maxima were as 100·1 or higher, with strong concentration of deposit associated with the edges of the skirts

Once deposits have significant thickness they have the secondary effect of modifying the airflow, both by increasing the frictional drag and by causing subsidiary vortices. Heavily convoluted insulators may become clogged as a result of such cumulative catch, with disastrous effects on the electrical performance by the loss of effective creepage path (Fig. 4.4).

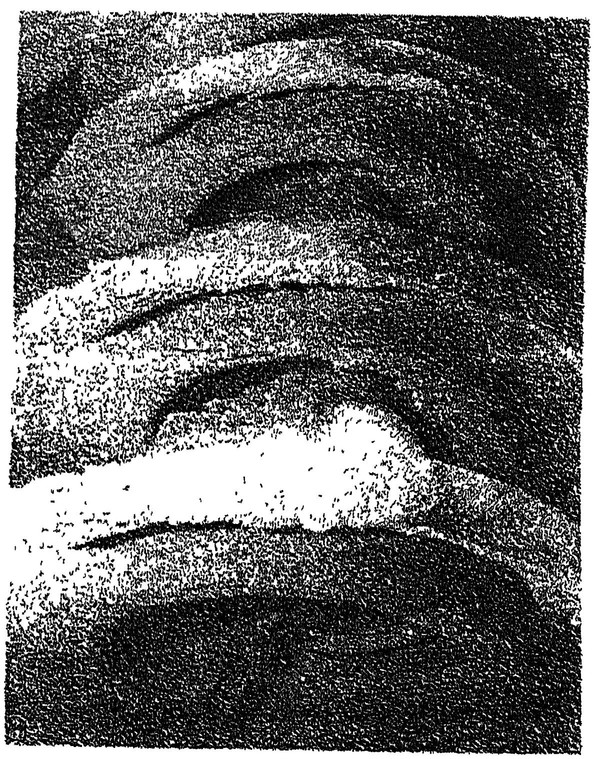


Fig 4.4 *Clogging: anti-fog insulator from bulky-polluted tower*

Effects of shape on aerodynamic deposition are less marked with different designs of large post or cylindrical insulator, since the flow is dominated by the central core.

Nevertheless, improved flow has been claimed for designs where only slight dishing of skirts has been used, with close spacing and alternate large and small diameters of skirt (Fig 4.5).

The impact of particles is considered, as a cause of pollution, but those impacts has also to be considered which may remove deposits. Raindrops range from about 0.1 to 4.0 mm in diameter and follow trajectories, even in high winds, which are much different from the flow lines They will hit and clean upper surface of insulators as well as cores and bluff edges of skirts, but will not penetrate into convolutions. Grains of sand, again of high density and diameter up to 0.1 mm, will similarly purge only outer surfaces. The so-called protected creepage on many convoluted insulators is thus seen often to be more in the nature of "protected dirt" (Fig. 4.6)

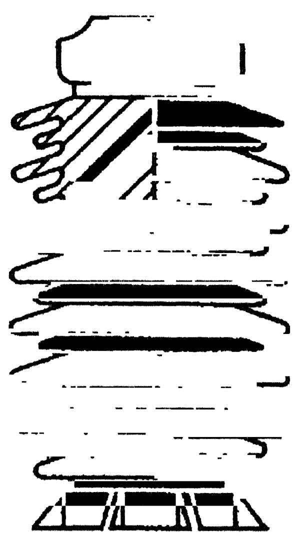


Fig. 4.5 *desert design post*

Closed-spaced sheds, lightly dished, promote low catch of pollution

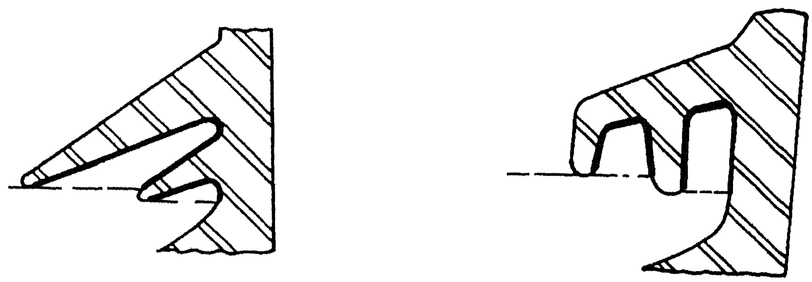
Thick central core perturbs air flow: design is subject to flashover under heavy wetting

The importance of aerodynamic effects in the pollution of insulators lies not only in their universality- every insulator, whatever its electrical condition, is subject to airborne

contaminants – but also in their long range Fine dust containing salt and dry plankton, which are generated by breaking of ocean waves, may be carried for tens or hundreds of kilometers to contaminate inland power lines; visible deposits of material blown from the Sahara are claimed to have been found in English car parks. Electric and magnetic fields act over relatively insignificant ranges.

Many airborne particles are electrically charged by turboelectric or frictional effects, and by attachment to ions generated from cosmic rays or industry Such particles will have an electric component of force added to their gravitational and aerodynamic ones, and will be caught when they come within range of appropriately charged DC electrodes, but will remain free in alternating fields.

Contamination processes are significantly different, for this reason between insulators on DC and AC circuits. Where corona activity causes large local ion fluxes, intense dirt deposition occurs, again on DC only, by electrostatic precipitator action.



a b

Fig. 4.6 *'protected' creepage*

Both shapes have 50-60% *'protected'* creepage (a) accessible to washing (b) Inaccessible; (a) has much better performance

The motion of particles having high permittivity into regions where the divergence of electric intensity is large, dielectrophoresis, is a very short-range effect, which, however, is polarity independent. The force depends on the volume, relative permittivity, but not the state of charge of the particle, and on the gradient of the square of the field intensity

$$F = \text{constant} \times v \times k-1/k+2 \text{ grad } E^2$$

Where F = force, v = volume, k = permittivity, E = intensity.

Evaporation of polluted raindrops has produced unexpected effects where deliberately greased surfaces are used Sufficient material has been collected to cause flashover on subsequent artificial wetting. Bird droppings, growth of moss and insect infestation have all caused flashover in special circumstances

4.3 Purging process

True self-cleaning by air flow, sometimes aided by suspended particles of relatively large size or mass, occurs on insulators and is promoted by designing the shape to maximise surface speeds. Purging of deposits by water depends for its efficacy not only on the shape of the insulator but also on the manner in which wetting occurs.

Raindrops, which are incident in high winds, are able to remove most types of pollution because of their impact speed Similarly, high pressure sprays and jets act principally because of their kinetic energy, although swirling action remove dirt from convolutions provided these are not too deep Both these types of wetting are subjected to the disadvantage that not all the water is bounced away from the surface after impact Where cascades result, there is an enhanced risk of flashover because the creepage path is short-circuited.

Light rain and drizzle will dissolve away the dangerous components of deposit, but generally leave behind any inert matter. Although this is a beneficial process it does call for the provisions of drip rings and the avoidance of shape of profile which can support continuous stream of solution (Fig 4.7). The biconvex shape, although ideal from the standpoint of low deposition, proved disastrous, in an out door trial for this reason. Even light rain will produce short circuiting of creepage if the catchment area is large and the shed spacing small: this is a probable cause of the poor performance of some large substation posts.

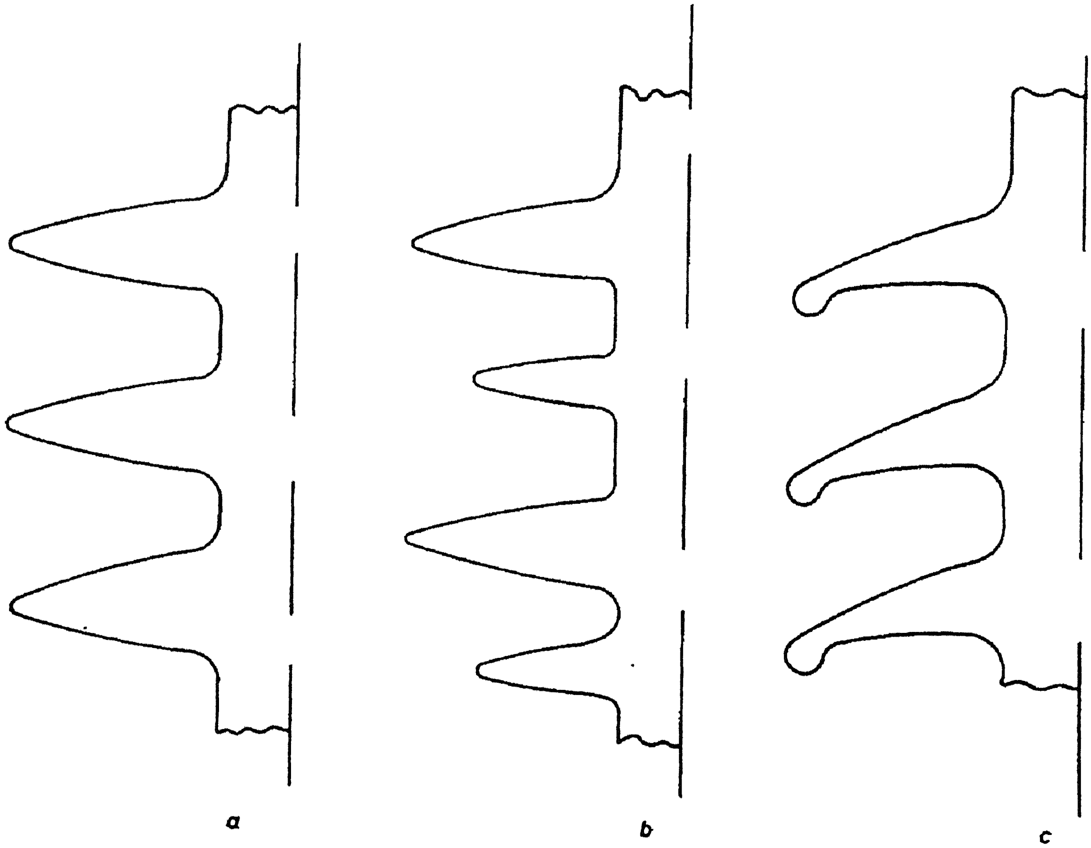


Fig 4.7 *Conflict between aerodynamics and draining*

a Minimum pollution catch : worst draining

B Practical case: closer sheds needed to compensate for lost creepage: poor draining

C Poor aerodynamics: good draining but drips causes short-circuits in heavy wetting

Very light wetting, by dew or fog, allows soluble to be leached out of deposited layers, i.e. to migrate down the concentration gradient. Some purging does arise from this cause even in locations of negligible rainfall.

True self-cleaning is of great importance in arid regions of negligible rainfall such as Arabian Gulf, and also in locations like railway tunnels. In so far as purging by water is concerned there are special difficulties in countries like Japan, where there are wide variations in contamination rate, including extreme deposition in typhoons, but also advantages in a good average rainfall and the possibility of using artificial washing as a supplement.

A purging process, which is confined, to polymeric insulators, is ablation of the surface. Housing materials which incorporate active filters like alumina trihydrate do show less contamination than some others: it seems that liberation of water vapour under attack by discharges, which give these fillers their valuable extinction function, may also dislodge deposited dirt. Other polymers which are subject to surface erosion by weathering, such as titanic loaded polyolefins, also show good ability to shed surface deposits: this is a variation on the old type of lead based paint, which preserved a white appearance by progressively losing both surface and dirt.

Live washing as a purging process has been mentioned, but other kinds of deliberate cleanings are also used. Cleaning by hand, sometimes with acids or solvents to remove obstinate deposits, is widely practiced. Initial surface treatment of the porcelain with waxes or oils aids manual cleaning, as does the cold setting silicone elastomer. Various dry blast processes are employed, generally on lower-voltage insulators, where relatively soft abrasives like powdered nutshells have to be employed to avoid glaze damage. All kinds of deliberate cleaning are expensive in manpower and outage time. Shapes or surfaces which are effective in lengthening the period between cleanings may therefore command higher purchase prices than the normal.

Chapter 5

Physics of pollution flashover

5.1 Flashover paradox

The apparent paradox in pollution flashover is that catastrophic electrical discharges are produced, spanning up to meters of air, by electrical potential differences capable, in ordinary circumstances, of being contained by air clearances of the order of few centimeters. In some way, the presence of feebly conducting deposits, on a surface which otherwise would be highly insulating, lowers the effective electric strength of the surface by a factor not far short of 100.

The underlying causes are two: the localized evaporation of a film of electrolyte gives rise to breaks in conductive film – the so called dry bands – across which electric stresses sufficient to ionize the air are generated; arcs in a gas, once established, can readily be extended without extinction by relatively slow separation of the electrodes between which they burn.

For much of its life an insulator will run with dry bands on its surfaces which are intermittently spanned by discharges. These discharges are harmless, apart from questions of possible interference generation and surface damage. Only very rarely will the combination of conductivity and electrical stress be sufficient to allow an arc to develop having sufficient current to make itself –sustaining under propagation: flashover then occurs. The technical hazard is that the surface conductivity, which causes a flashover, persists after the arc has been cleared by the operation of the protection, allowing subsequent flashover to occur. A reduced system security persists until the causes are removed.

5.2 Stages of the flashover process

Common precursors of pollution flashover on insulators in actual service are the following:

(a) Arrival of nearly pure water, as dew, rain or mist, at an insulator which carries a burden of pollution comprising soluble ionic components like common salt

(b) Deposition of droplets from marine or industrial fogs, or of other combination of water and electrolyte

(c) Build up of hoarfrost, freezing fog or ice on the fouled surface of an insulator, the ionic components of the fouling then proceedings to depress the freezing point of the water and allow solution at the interface.

(d) Switching in of a circuit containing insulators, which are wet and fouled.

(e) Arrival of a temporary over voltage or of switching surge, at an insulator, which is wet, fouled and possibly energized.

Of these cases (a) is the most common. Especially in desert areas, pollution flashover occurrences are closely correlated with times of dew and morning mist, while in marine polluted regions the dangerous times are in still-air fog. Simultaneous deposits of water and solute occur in on-shore storms and, rarely when insulators are immersed in chimney plumes. The selection of this case, (b), for salt-fog testing therefore departs from generality.

The freezing-fog condition (c) has given rise to some of the most serious incidents; for example, in1962 to multiple failures and temporary breakup of the English transmission network. The offending layer of electrolyte is effectively sealed on to the insulator and requires manual removal. The remaining cases, (d) and (e), though less common, throw an interesting light on the flashover processes.

Chapter 6

A case study- Flashover on 400 kV Obra-Kanpur transmission line

400 kV Obra- Kanpur UPSEB transmission line is a twin bundle conductor per phase single circuit line. In each phase strain insulator strings consist of two parallel strings of 22-160kN insulators. Suspension insulator strings consisted of single string of 23-120kN insulators.
The three phases lay in the horizontal plane with a distance of 6m between adjacent phases.
This experimental work was divided into three parts

6.1 Study of the area and past history of the flashover problem

6 2 Chemical analysis of pollutants

6.3 Experimental work in laboratory

6.1 History of the flashover problem at the location

Since 1992-93 during the months of December and January, under dense fog condition, this line has witnessed flashovers on the insulator over a length 4-5km situated near Naubasta in Kanpur. this area has mushrooming growth of unauthorised kilns for making " black salt " artificially just very close to a number of this 400 kV line towers.

Before the flashover problem arose, insulator strings consisted of normal insulators. First time, flashover occurred in the middle phase insulator string of a tension string. After the recurrence of flashovers in the middle phase, the insulators of all phases on a length of 4-5 km were replaced by antifog insulators. After two years flashovers started taking place again in the middle phase. This time only middle phase insulators were replaced. Next year

flashover problem was sighted at the corner phase. Strain insulator strings were witnessing flashover problem more frequently than suspension strings even when salt kilns were closer to suspension string It was observed that once replaced, insulators passed two seasons without flashovers.

On investigating the area, it was observed that only difference with this span of line is the presence of black salt kilns near to the transmission lines. The fumes of the salt get deposited over the insulators and the tower during the manufacturing process. It was also observed that towers have the signs of excessive rust. Even in the residential area closer to these black salt kilns, windows and gates made of iron show signs of extensive corrosion

6.2 Chemical analysis of pollution layer deposits:

The constituents of pollution were analysed with the help of X-ray diffraction spectrometer. Different elements found in the pollutants are following:

Nacl

$Caso_4$

$Caso_4 2h_2o$

KCl

$Zncl_2$

$Cacl_2$

$Na_2SO_3 . 7H_2O$

KOH

KI ESELGOR

AEROSOL

6.3 Experimental work in laboratory

It was desirable to simulate the conditions leading to flashover on the insulators as closely as possible in the laboratory on the insulator string of the transmission line. Therefore four single insulators of the actual line were chosen out of which two were used

one and other two were new. Out of these two were of 160kN and two were of 120kN ratings. All the insulators were supplied by the UPSEB.

Single insulator discs were hanged vertically The ground wire was connected at the conical top of the disc. At the lower part of the disc voltage was applied

Following sets of experiments were performed: -

Tests performed under clean condition

(1) Flashover tests under no fog no pollution condition.

Energisation under constant voltage for 1 hr at 30kV and then increasing up voltage up to flashover

Measurement of creepage current on gradually increasing voltage up to flashover.

(2) Flashover test under clean and wet condition (Simply wetted by fine spray)

Gradually increasing voltage from zero to flashover

Measurement of creepage current by gradually increasing voltage up to flashover

Tests performed under polluted condition

(1) Flashover test under dry and polluted condition

Energisation under constant voltage for 1hr. at 30kV and then increasing voltage up to Flashover.

Measurement of creepage current by gradually increasing voltage up to flashover.

(2) Flashover test under wet and polluted condition

Gradually increasing voltage from zero to flashover.

Measurement of creepage current by gradually increasing voltage up to flashover.

To create the condition of the insulator under fog, water was sprayed on it through a fine spray nozzle. The insulator was left under this condition for 3 minutes before application of voltage. Polluted condition was created by first spraying water on clean surface and then spraying dust on wet insulators. This process was repeatedly carried out to ensure real pollution condition. This pollution layer dust was especially collected and brought from the area where insulators have been witnessing such flashovers.

All the other grounded objects, other than the insulator top were kept at least half a meter away. This was done to prevent the flashover between insulator disc and other objects and also to minimize stray capacitances.

The setup was discharge after each application of high voltage with the help of a " discharge rod".

Chapter 7

Experimental Setup

The experimental setup can be broadly divided into following three sections.

- Power supply
- Insulator stand
- Test and measuring instruments

7.1 High voltage ac power supply

A variable ac power supply was obtained from the existing 100-kV/50 kVA/ 50 HZ, partial discharge free, single-phase test transformer. The input power to the test transformer was derived from a 100kVA single phase, oil cooled, motorized autotransformer which was regulated from the control panel. The output of the test transformer was applied on the lower part of specimen insulator discs.

7.2 Insulator stand

To provide proper clearance from the ground and supply, an insulator string made of toughened glass was hanged from the roof of the laboratory. Specimen insulator was connected at the bottom of this string. The other insulator in the string was of glass type. The string performed two functions:

- provided mechanical support to the specimen insulator
- provided insulation between the high voltage supply and the roof.

7.3 Test and measuring instruments

Following measurements were performed in this experimental work·

- (a) Measurement of creepage current
- (b) Measurement of flashover voltage
- (c) Recording of leakage current waveform

7.3.1. Electrical measurements

Following equipment were used for the measurement and recording of electrical quantities like current and voltages

- MOTWANE make 3 ½ digit Digital multimeter (model-DM 352), for voltages up to 1 kV
- Control panel meters of the 100 kV test transformer for ac voltages.
- TEKTRONIX TDS 200-Series, Digital Real – Time Oscilloscope for monitoring and storing the creepage current and supply voltage waveforms.
- RS-232 interface for connectivity from oscilloscope to computer.
- PC for storing the creepage current and supply voltage waveforms.
- Hewlett Packard deskjet 610C printer for printing waveforms stored in computer.

7.4 Current Sensing Resistor

A wire wound non-inductive resistance of 1.0 ohm was used for viewing the waveform of the creepage current on oscilloscope. A two-meter long Nichrome wire was wound on a bakelite bobbin in a bifiliar fashion to give a non-inductive resistance. This assembly was enclosed in a metallic enclosure, which provided shielding against electromagnetic interference. The two ends of the resistor were brought out through co-axial cables for interconnections.

7.5 Measurement circuits

In these experiments three different setups were used:

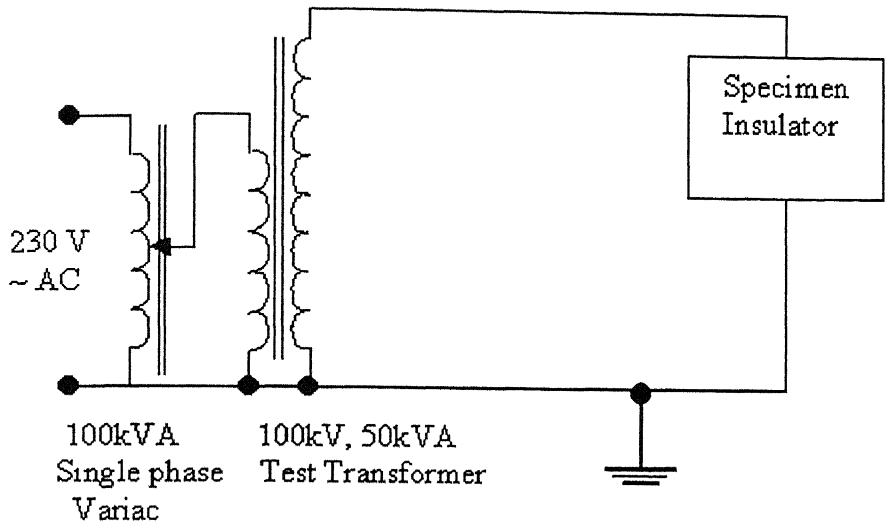


Fig. 7.1 Circuit diagram used for measuring flashover voltages under different condition

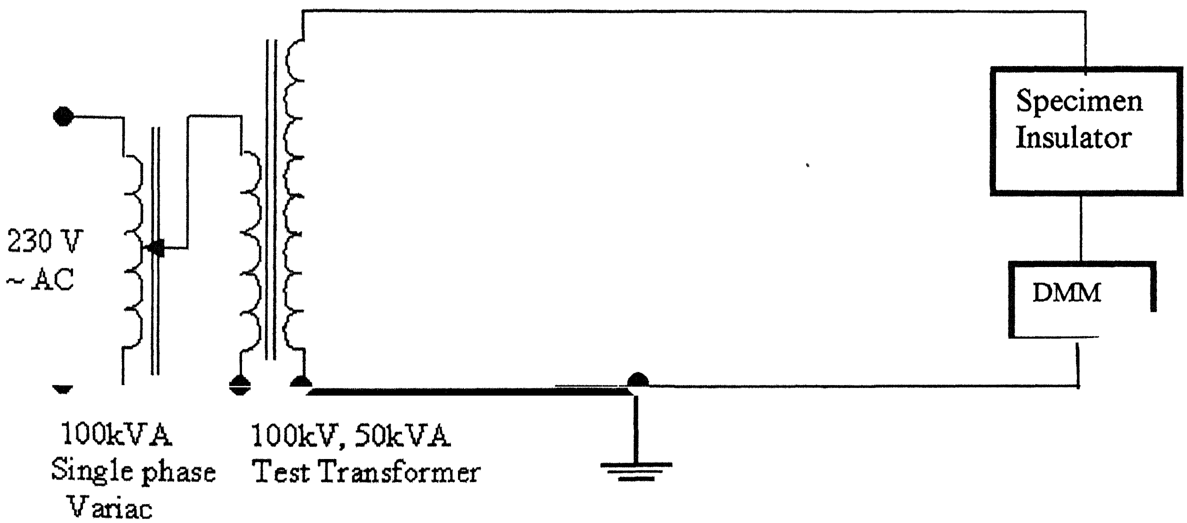


Fig. 7.2 Circuit diagram of the setup with measurement of creepage current

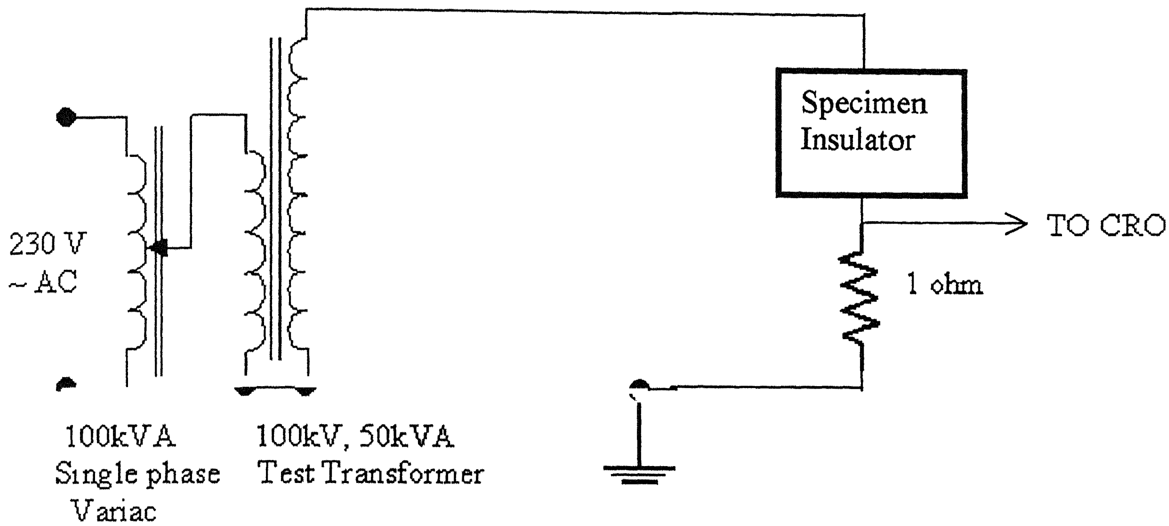


Fig. 7.3 Circuit diagram of the setup for recording creepage current

Chapter 8

Results and discussion

1 As the voltage applied on the wet and polluted insulator was increased, considerable creepage current was measured The creepage current first increased excessively which must have found its path through least resistance channel but only for a short time because of the disappearance of least resistance path due to the heat generated by the creepage current and also due to the physical movement of pollution particles.

2. It was observed on CRO that at lower voltage creepage current waveform was distorted sinusoidal.

3. At higher voltages (>30 kV) this current accompanied with very high pulse current peaks. These pulse current peaks could be because of the presence of vigorous surface discharges (tracking) present under the condition.

4. It was observed on actual line that middle phase was more susceptible to flashovers than the side phases. Calculations showed that middle phase had higher surface voltage gradient than side ones (Appendix B).

5. Under clean and dry conditions, it was observed that creepage current increased gradually on increasing the voltage. Creepage current was very small initially like .05 mA at 5 kV and even at 60 kV it was not more than 1.52 mA for 120kN old insulator. It could be observed that at clean and dry condition creepage current losses were negligible.

6. Under clean and wet conditions, it was observed that creepage current shot up to a high value reduction in creepage current took place. This could be because of the drying of the insulator surface due to increase in the temperature of the surface.

7 Under polluted and dry conditions, creepage current was found to increase gradually on increasing the applied voltage. Creepage current was very small initially like .06 mA at 5 kV and even at a voltage of 60 kV, it was around 1.56 mA for 160 kN old insulator. Thus there was no difference in the magnitude of creepage current measured under clean-dry and polluted-dry condition.

8. Under polluted and wet conditions, at lower voltages creepage current was measured to be very high. It was 8.2mA at 1kV and at 7kV itself it was 25 mA for 160 kN new insulator.

   But as voltage was increased further, surface conditions appears to have changed and surface became probably drier. This resulted in reduced creepage current and it got stabilized in the range of 1.5 – 1.8 mA for voltages between 14 – 20 kV for 160 kN for new insulator.

9. It has been observed that at lower voltages inspite of higher creepage current, no flashover occurred. Whereas at higher voltages flashover occurred even at lower creepage current levels.

10. Under clean and dry condition, no flashover occurred even at very high voltages such as:

    For 120 kN old – no breakdown up to 92 kV

    For 120 kN new - no breakdown up to 95 kV

    For 160 kN old – no breakdown up to 92.5 kV

    For 160 kN new - no breakdown up to 98 kV

    Since the rating of test transformer was 100 kV it was not possible to go beyond this level of voltage required for measuring flashover voltages under the conditions. It can be clearly concluded that there is no significant difference

between the dielectric strength of old and new insulators under clean and dry conditions. Also both 120 kN and 160 kN insulators have similar dielectric strength.

11. Under clean and wet conditions, it was observed that flashovers occurred at relatively very higher voltage such as .

For 120 kN old – between 50 to 60 kV

For 120 kN new -between 65 to 70 kV

For 160 kN old – between 50 to 60 kV

For 160 kN new – between 70 to 80 kV

It can be concluded that there is a significant deterioration in the insulating properties between the new to old insulators under clean and wet condition Both 120 kN and 160 kN insulators have shown similarity in behaviour.

12. Under polluted and dry conditions, it was observed that flashover occur at relatively higher voltage than clean and wet conditions, such as –

For 120 kN old – between 70 to 80 kV

For 120 kN new – no flashover till 85 kV

For 160 kN old – between 75 to 85 kV

For 160 kN new – between 85 to 90 kV

Under this condition significant deterioration in insulating properties is evident between old and new insulators again. Both 120 kN and 160 kN insulators show similar dielectric behaviour.

13. Under polluted and wet conditions, flashovers have been seen at considerably lower voltages such as -

For 120 kN old – between 7 to 23 kV

For 120 kN new – between 23 to 25 kV

For 160 kN old – between 9 to 27 kV

For 160 kN new – between 24 to 32.5 kV

A sharp decrease in insulating properties can be observed from polluted and dry to polluted and wet condition. Both 120 kN and 160 kN insulators show similar

behavior irrespective of their shape. Further it can be observed that the worst case is for the old insulators having wet pollution layer dust deposits.

14 As it is an established fact that horizontal string of insulator deals more effectively flashovers than vertical string of insulators But the flashover history of this particular problem shows that horizontal string of insulators in case of tension tower is affected in same manner as vertical string of insulators in case of suspension tower.

15. Voltage distribution across the string of suspension insulator is calculated. In these calculations inclination of tower with vertical and effect of corona ring is neglected. Voltage across the insulator nearest to conductor came around 43.337 kV. Flashover voltages falls below 10 kV under polluted and wet condition. Under all other circumstances flashover voltage was above 43.337 kV. This is the reason why flashover occurs only in the months of December and January (Appendix D).

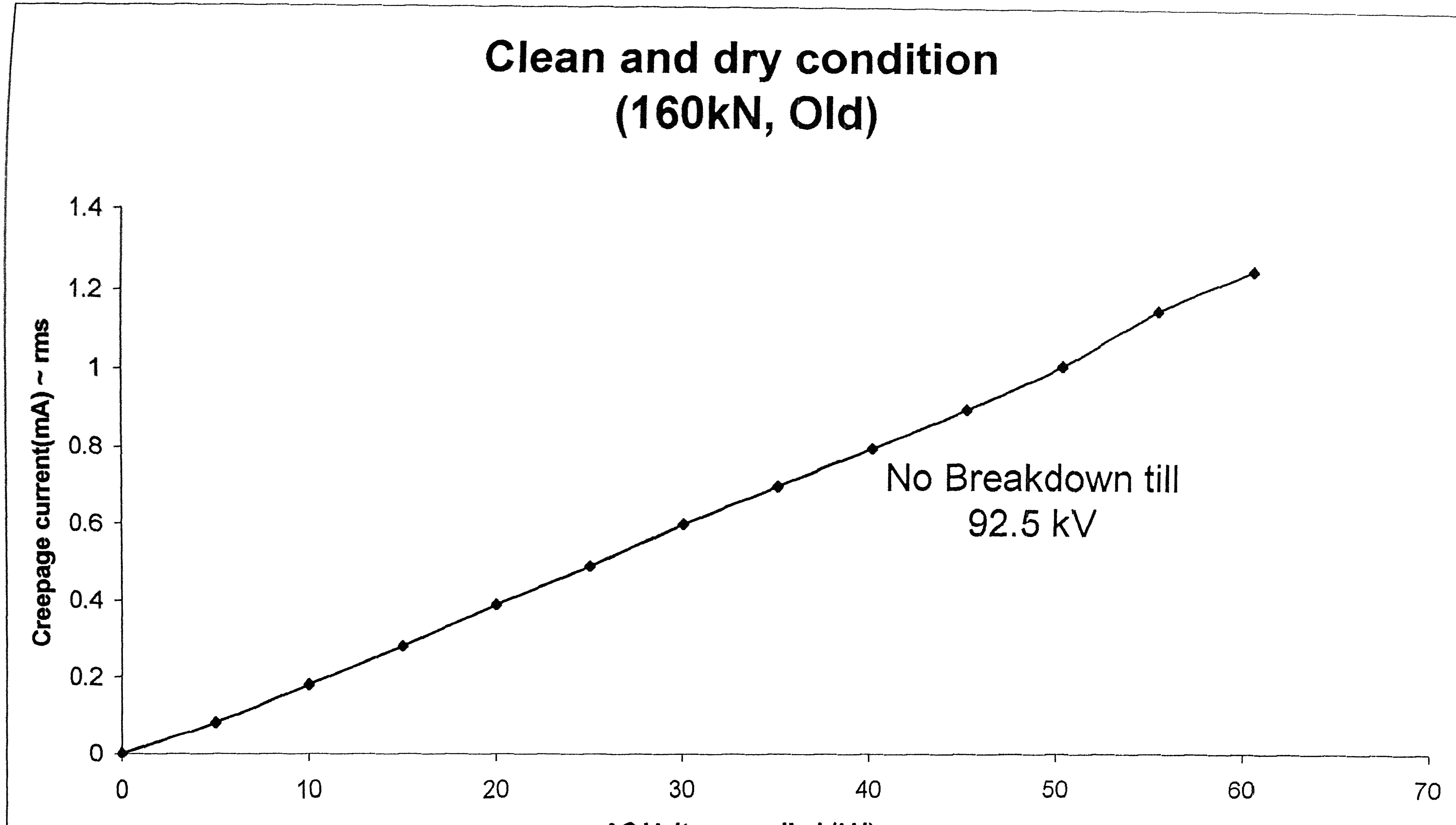
16. There was not much difference seen between the values of old and new insulator in terms of capacitance value. Capacitance's of all four given insulators were measured through Schering bridge. The capacitance values are –

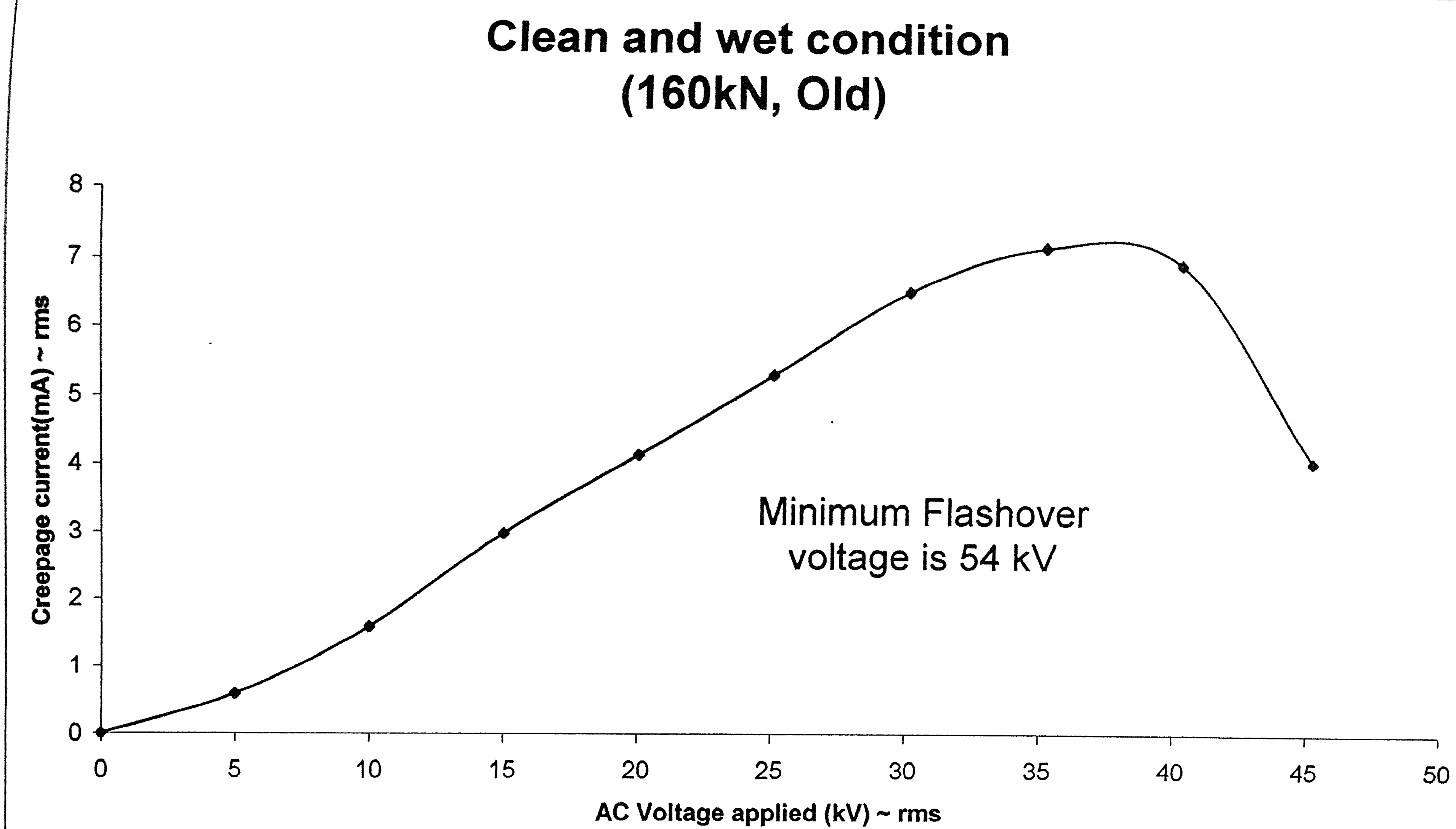
160 kN old Insulator – 56.49 pF

120 kN old Insulator – 44.64 pF

160 kN new Insulator – 59.17 pF

120 kN new Insulator – 46.68 pF


Clean and dry condition
(160kN, Old)
Creepage current(mA) ~ rms
1.4
1.2
1
0.8
0.6
0.4
0.2
0
No Breakdown till
92.5 kV
0
10
20
30
40
50
60
70
AC Voltage applied (kV) ~ rms
Figure 8.1


Clean and wet condition
(160kN, Old)
Creepage current(mA) ~ rms
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
50
AC Voltage applied (kV) ~ rms
Minimum Flashover
voltage is 54 kV
Figure 8.2

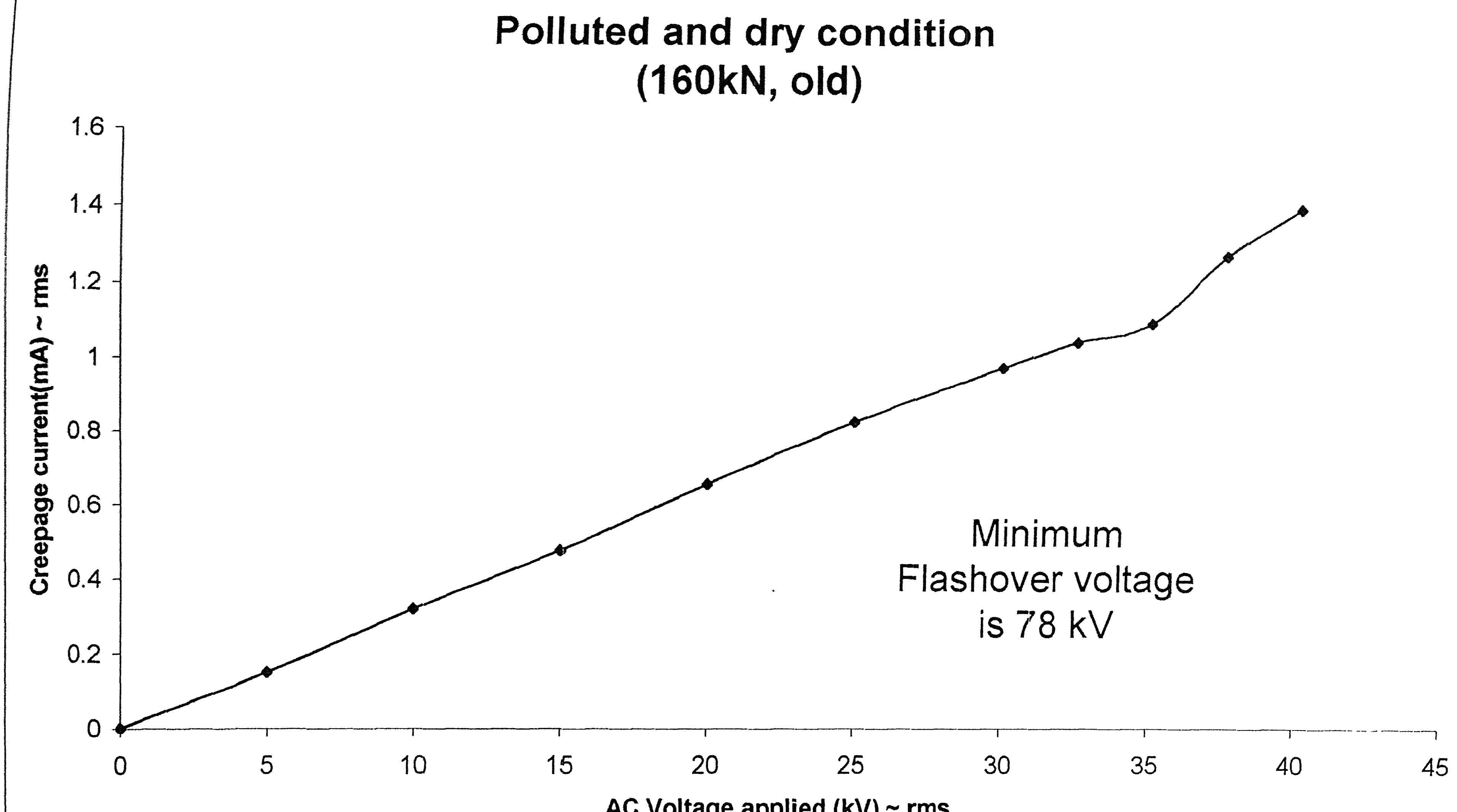
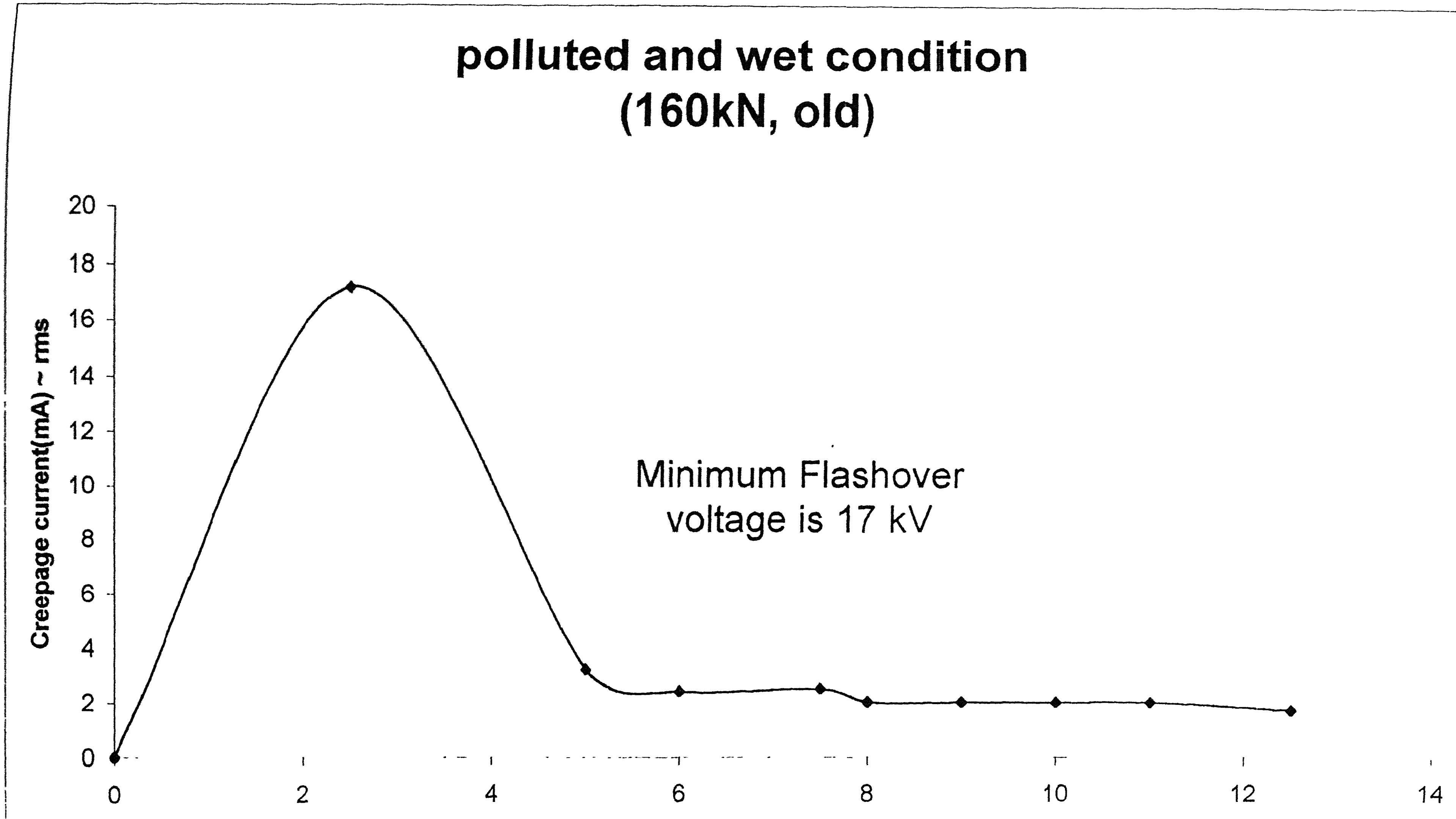
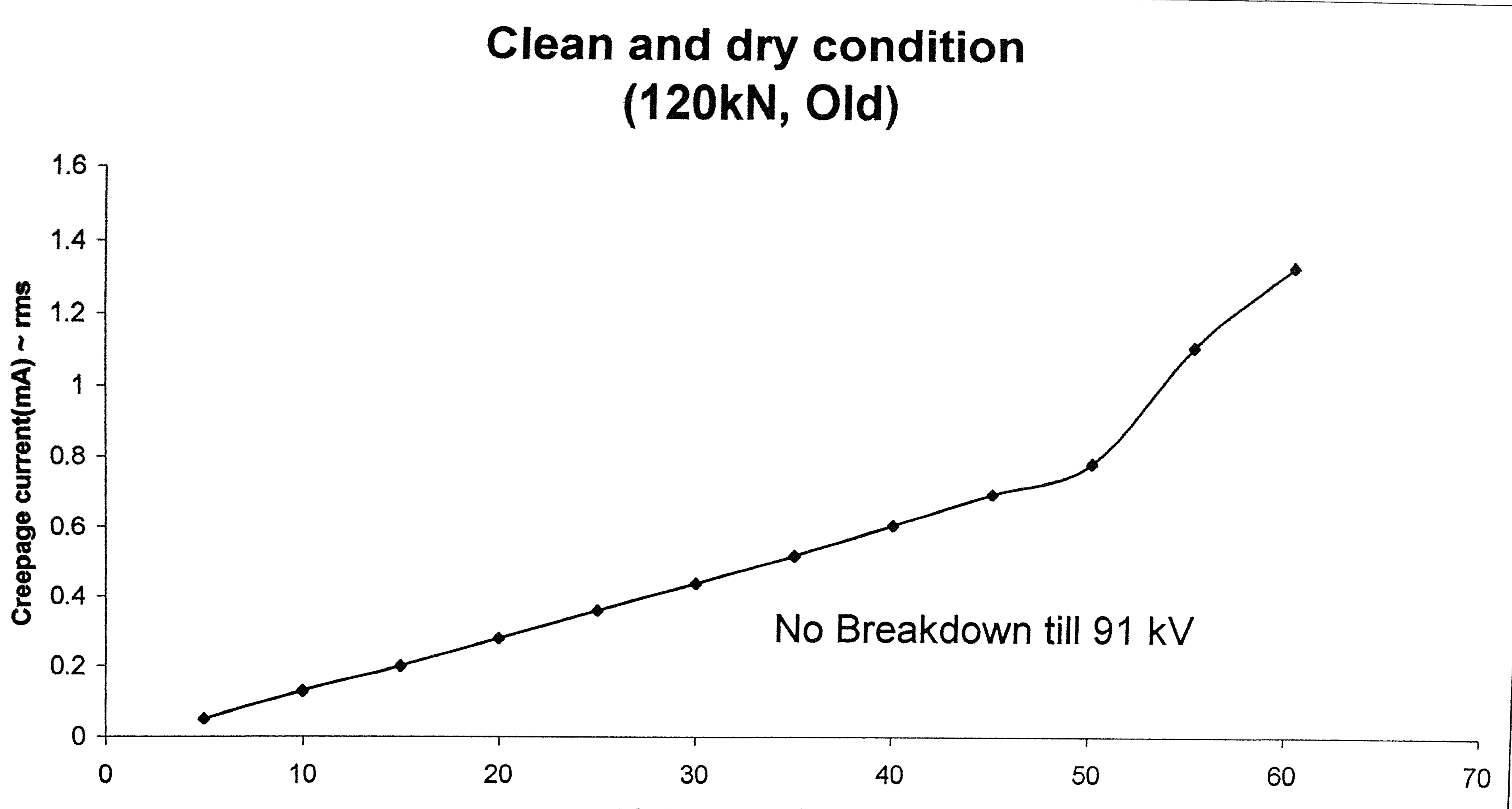

Polluted and dry condition
(160kN, old)
Creepage current(mA) ~ rms
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
Minimum
Flashover voltage
is 78 kV
AC Voltage applied (kV) ~ rms

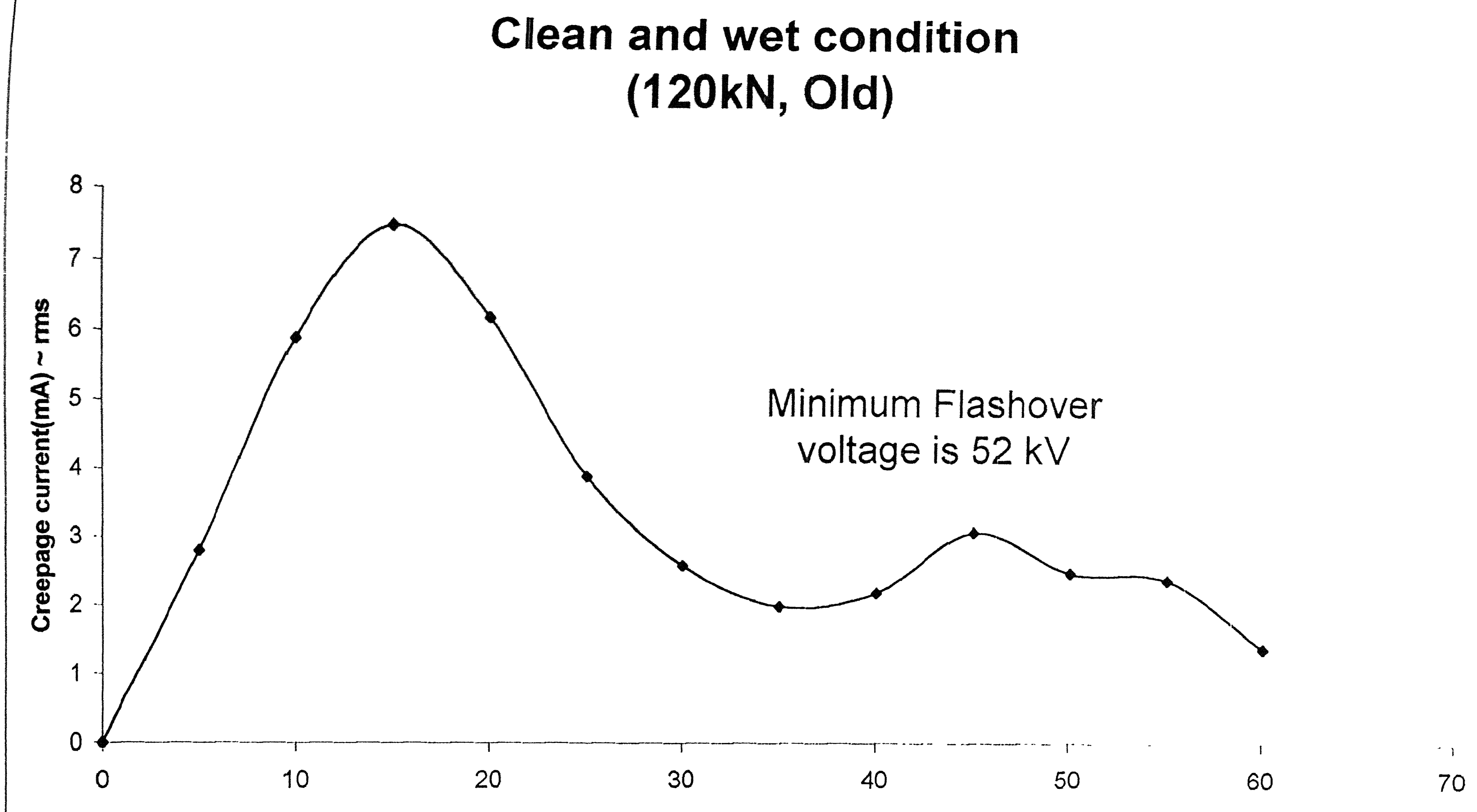
Figure 8.3

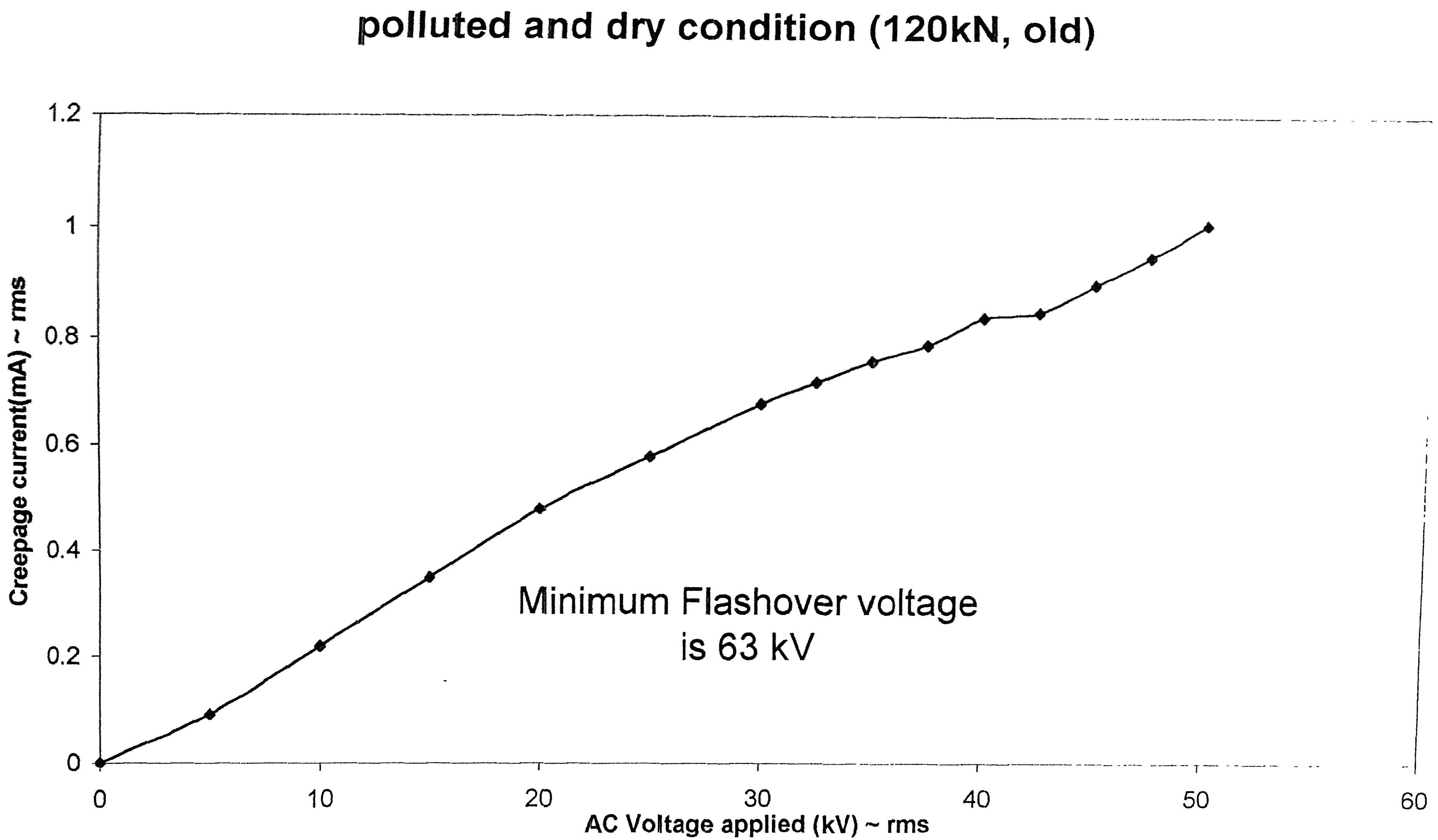

polluted and wet condition
(160kN, old)
Creepage current(mA) ~ rms
20
18
16
14
12
10
8
6
4
2
0
Minimum Flashover
voltage is 17 kV
0
2
4
6
8
10
12
14
AC Voltage applied (kV) ~ rms
Figure 8.4



Clean and dry condition
(120kN, Old)
Creepage current(mA) ~ rms
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
No Breakdown till 91 kV
0
10
20
30
40
50
60
70
AC Voltage applied (kV) ~ rms

Figure 8.5


Clean and wet condition
(120kN, Old)
Creepage current(mA) ~ rms
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
70
Minimum Flashover
voltage is 52 kV
AC Voltage applied (kV) ~ rms
Figure 8.6


polluted and dry condition (120kN, old)
Creepage current(mA) ~ rms
1.2
1
0.8
0.6
0.4
0.2
0
Minimum Flashover voltage
is 63 kV
0
10
20
30
40
50
60
AC Voltage applied (kV) ~ rms
Figure 8.7

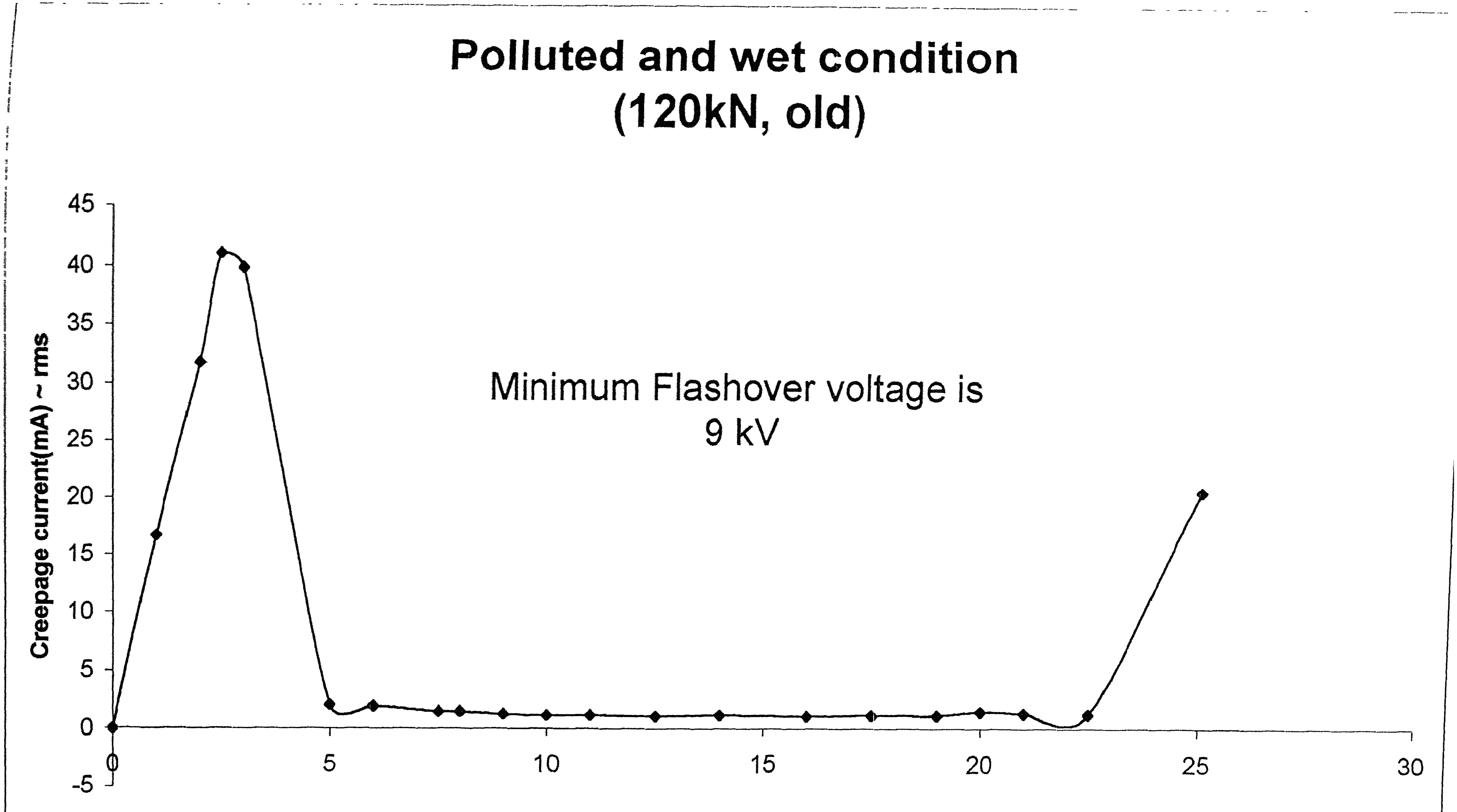
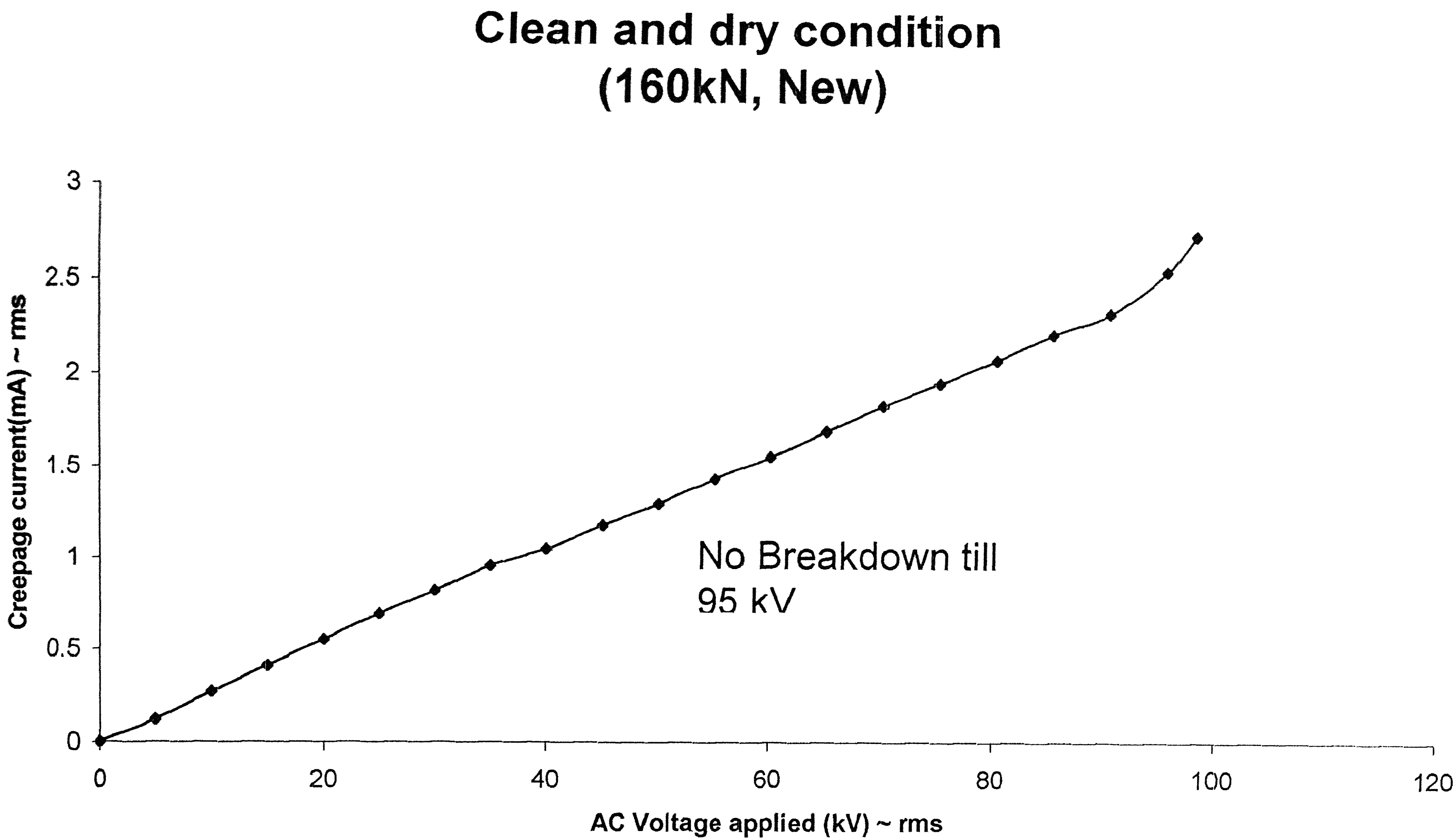
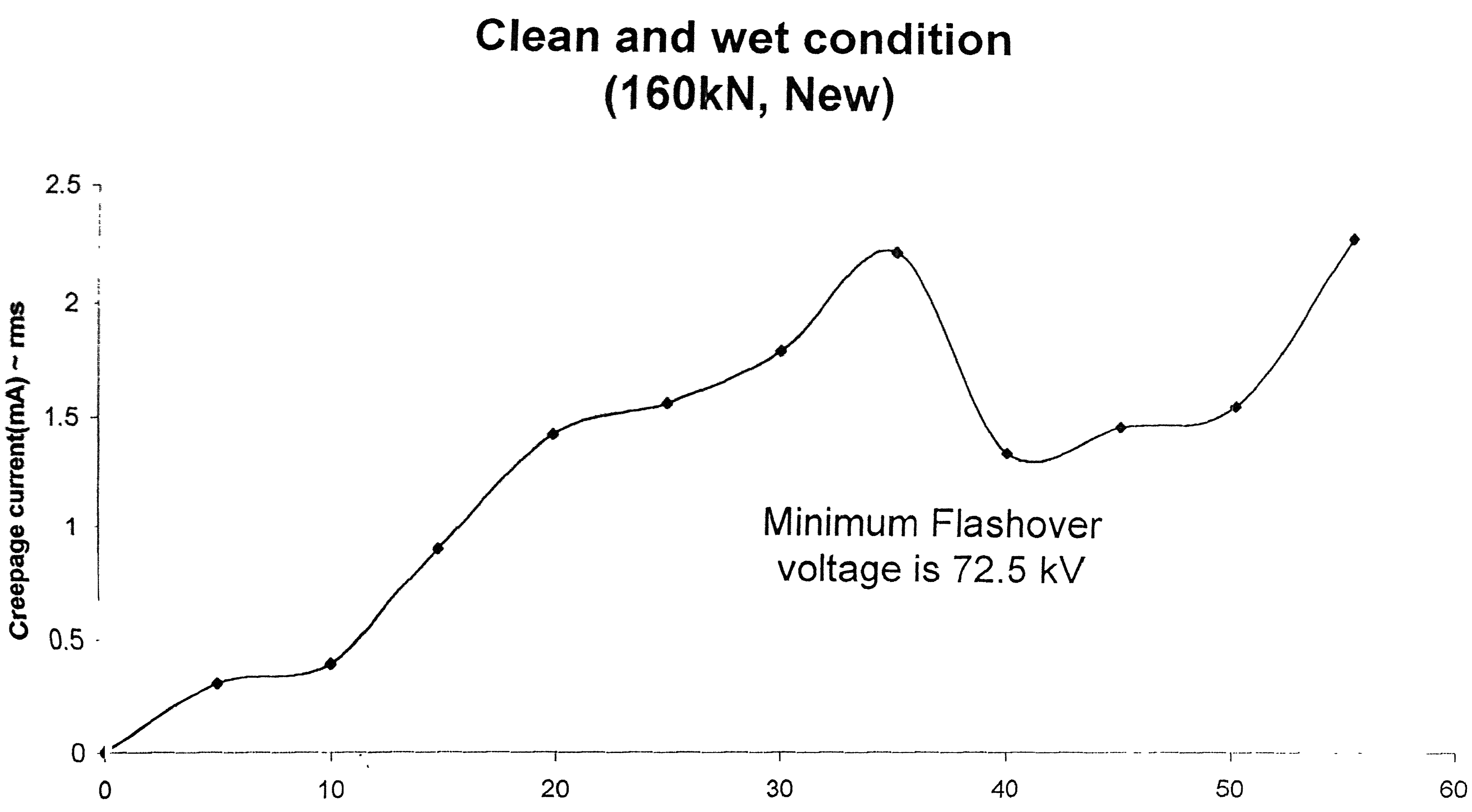

Polluted and wet condition
(120kN, old)
Minimum Flashover voltage is
9 kV
Creepage current(mA) ~ rms
45
40
35
30
25
20
15
10
5
0
-5
0
5
10
15
20
25
30
AC Voltage applied (kV) ~ rms

Figure 8.8



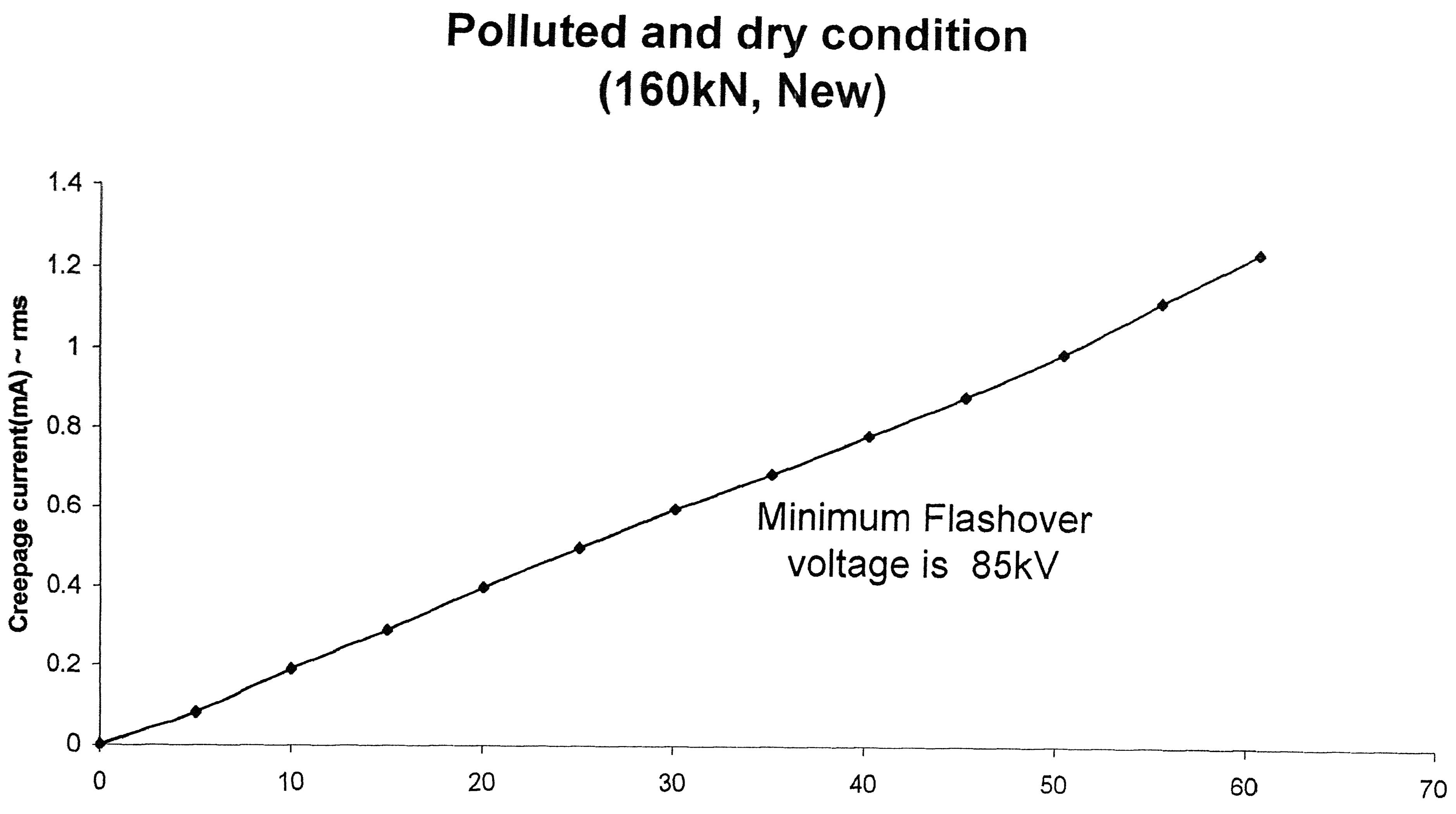
Clean and dry condition
(160kN, New)
Creepage current(mA) ~ rms
3
2.5
2
1.5
1
0.5
0
No Breakdown till
95 kV
0
20
40
60
80
100
120
AC Voltage applied (kV) ~ rms

Figure 8.9



Clean and wet condition
(160kN, New)
Creepage current(mA) ~ rms
2.5
2
1.5
1
0.5
0
Minimum Flashover
voltage is 72.5 kV
0
10
20
30
40
50
60
AC Voltage applied (kV) ~ rms

Figure 8.10


Polluted and dry condition
(160kN, New)
Creepage current(mA) ~ rms
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
Minimum Flashover
voltage is 85kV
AC Voltage applied (kV) ~ rms
Figure 8.11

Polluted and wet condition (160kN, New)

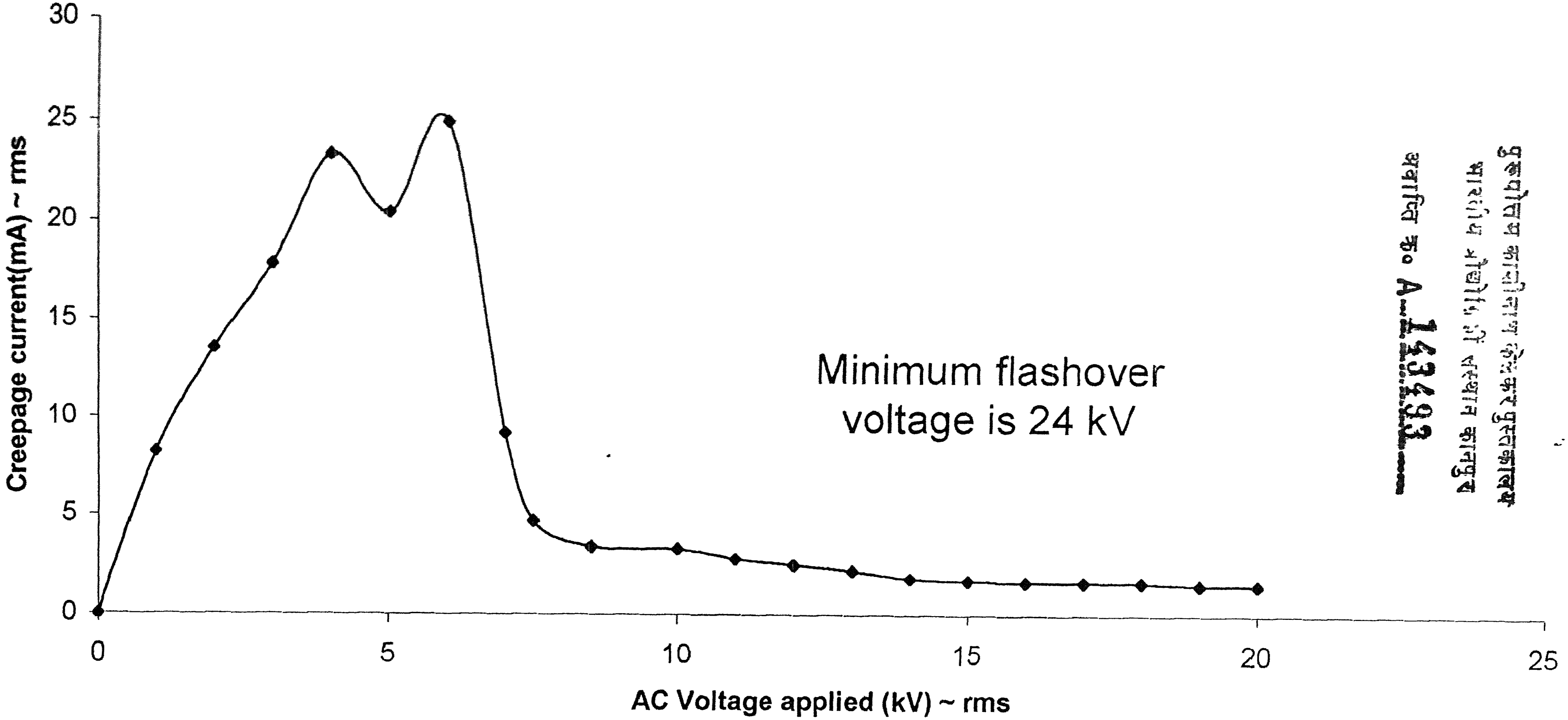
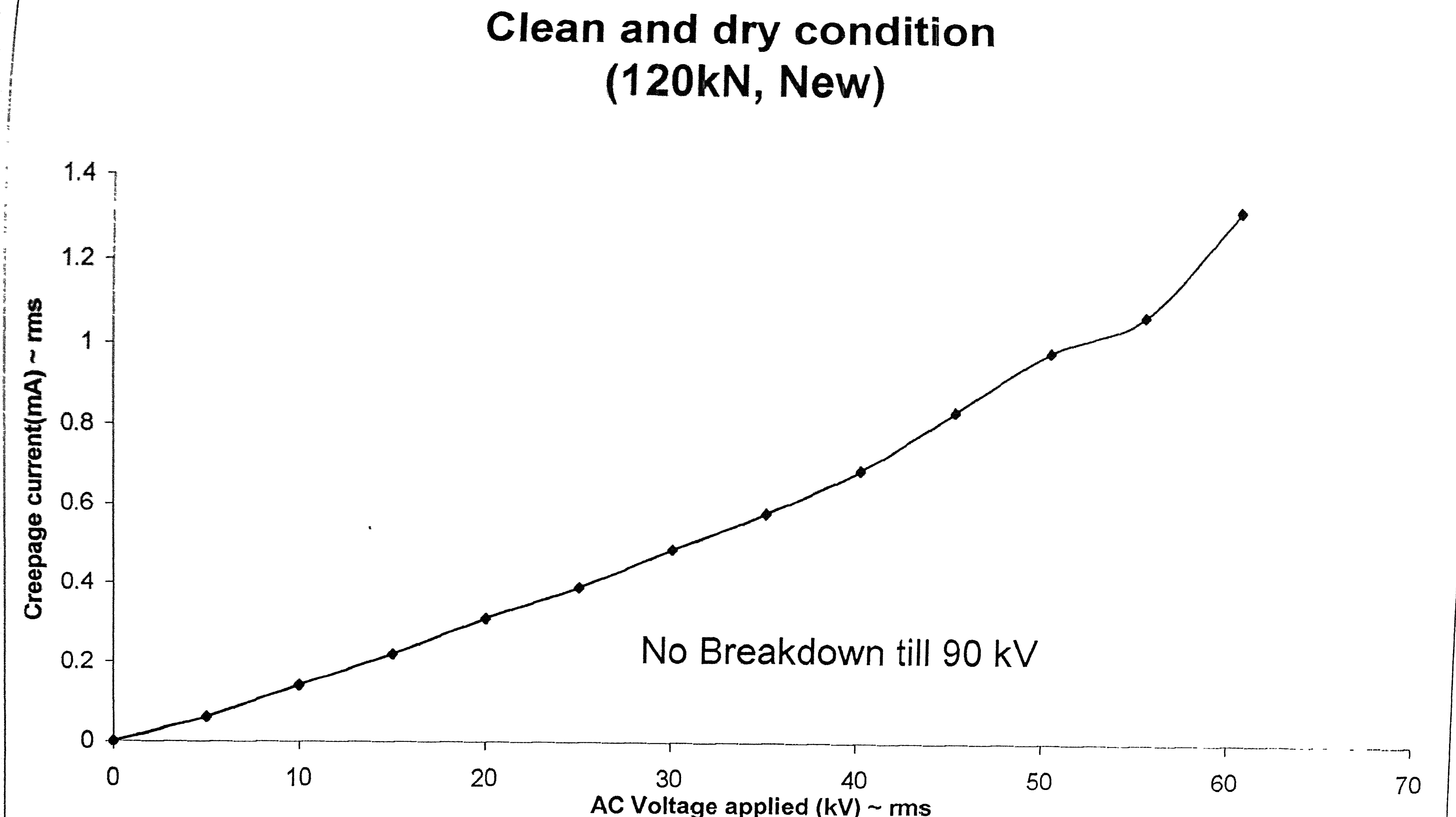
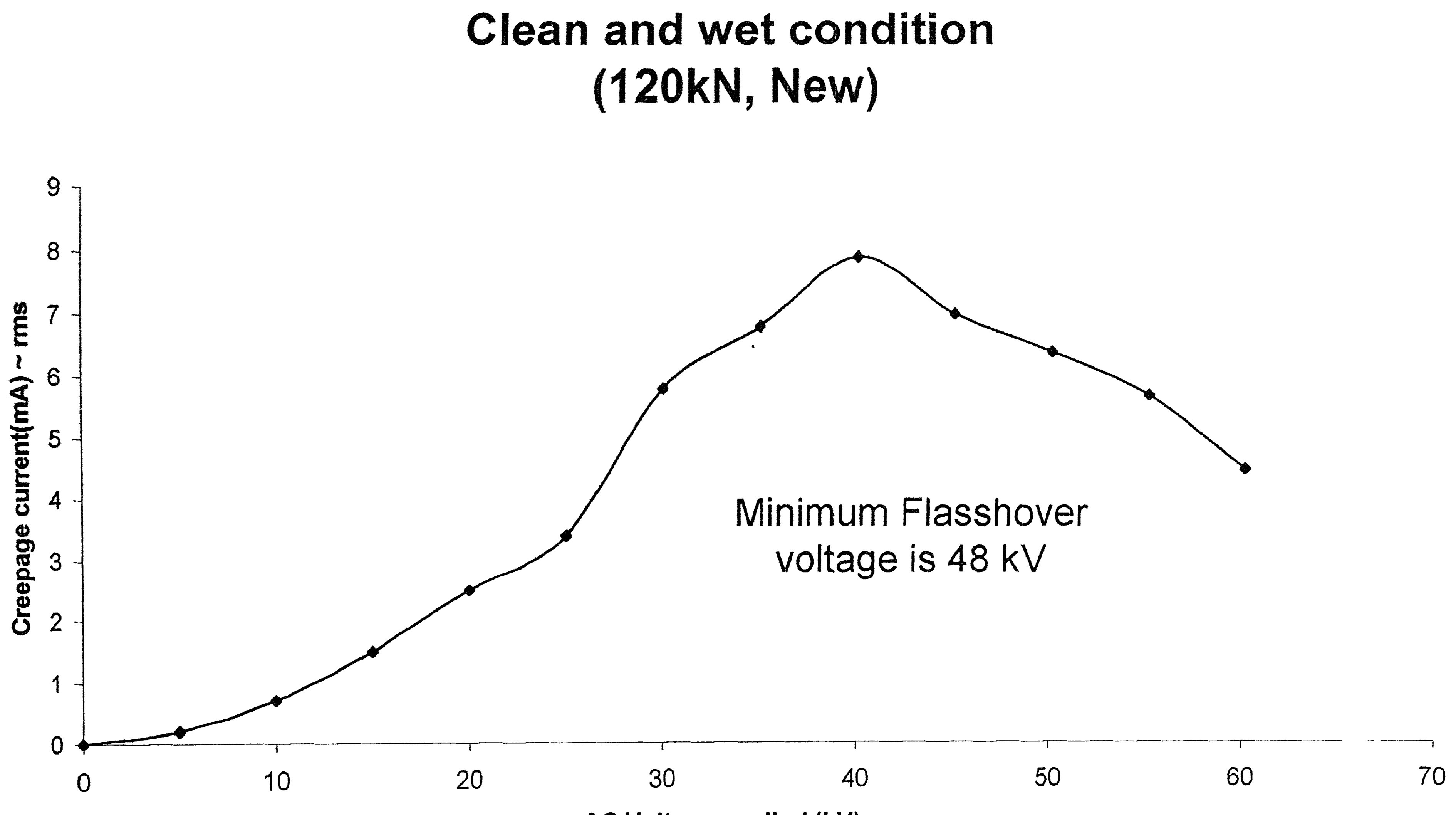
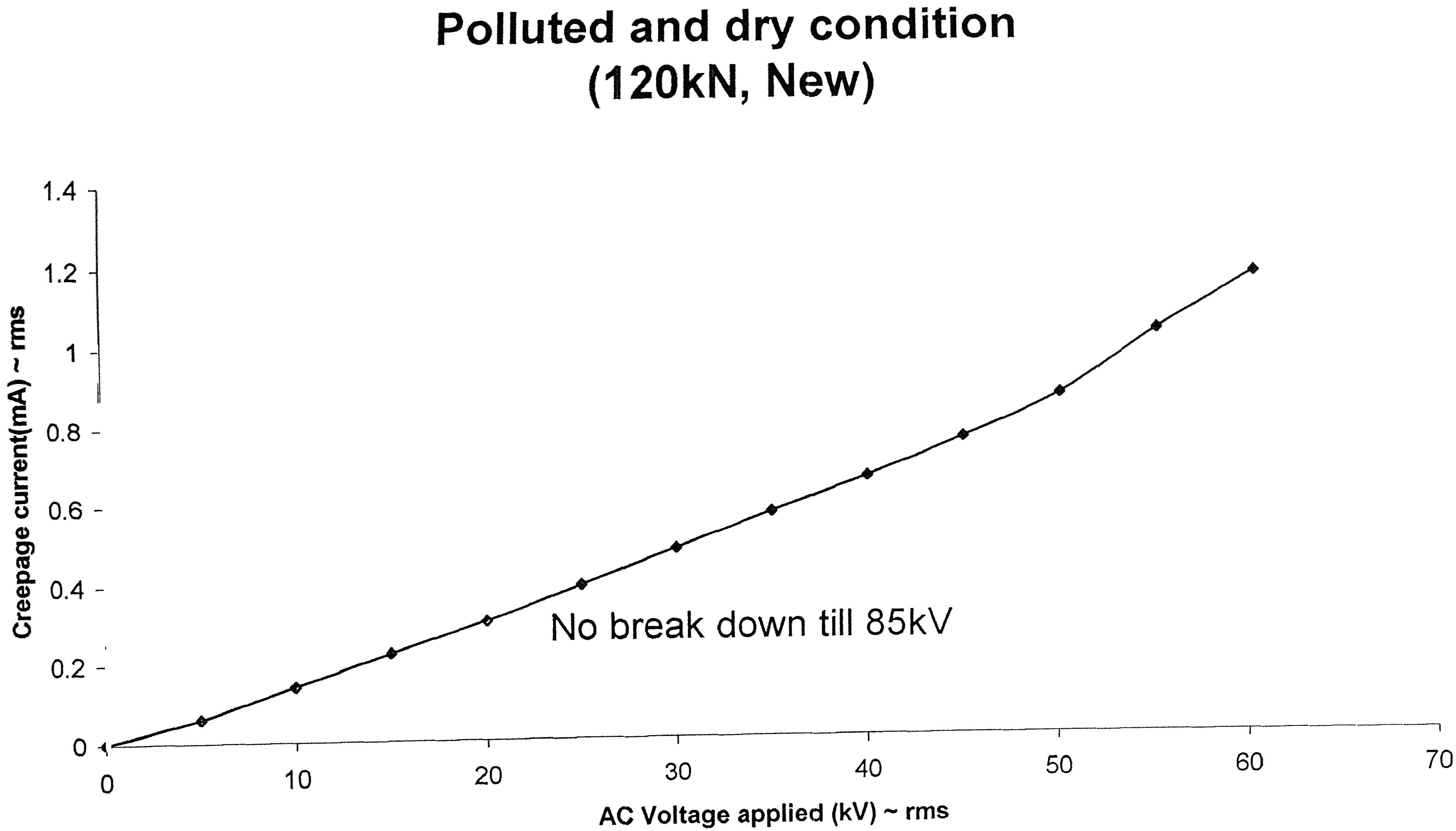


Figure 8.12


Clean and dry condition
(120kN, New)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Creepage current(mA) ~ rms
No Breakdown till 90 kV
0
10
20
30
40
50
60
70
AC Voltage applied (kV) ~ rms
Figure 8.13


Clean and wet condition
(120kN, New)
Creepage current(mA) ~ rms
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
Minimum Flasshover
voltage is 48 kV
AC Voltage applied (kV) ~ rms
Figure 8.14


Polluted and dry condition
(120kN, New)
Creepage current(mA) ~ rms
1.4
1.2
1
0.8
0.6
0.4
0.2
0
No break down till 85kV
0
10
20
30
40
50
60
70
AC Voltage applied (kV) ~ rms
Figure 8.15

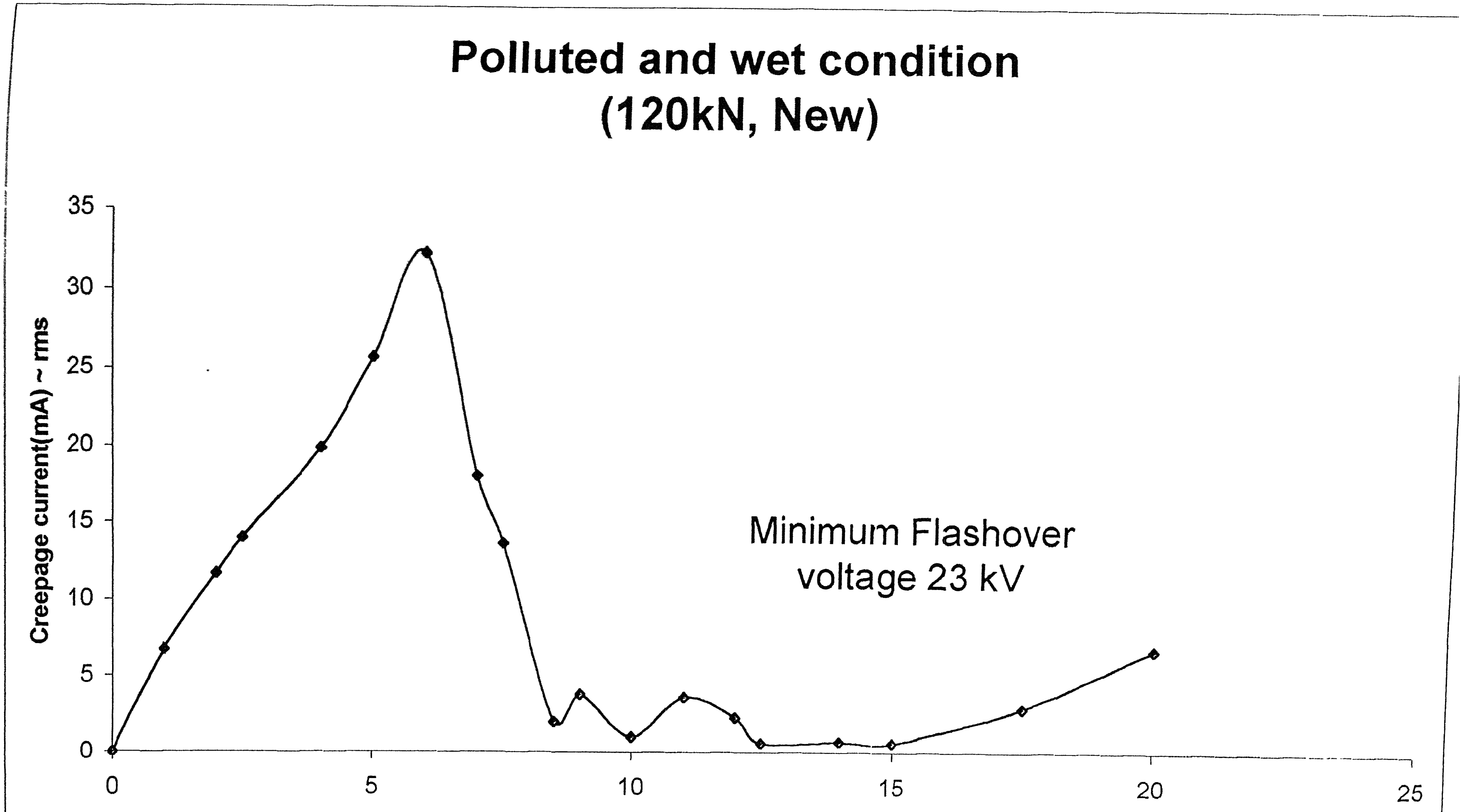
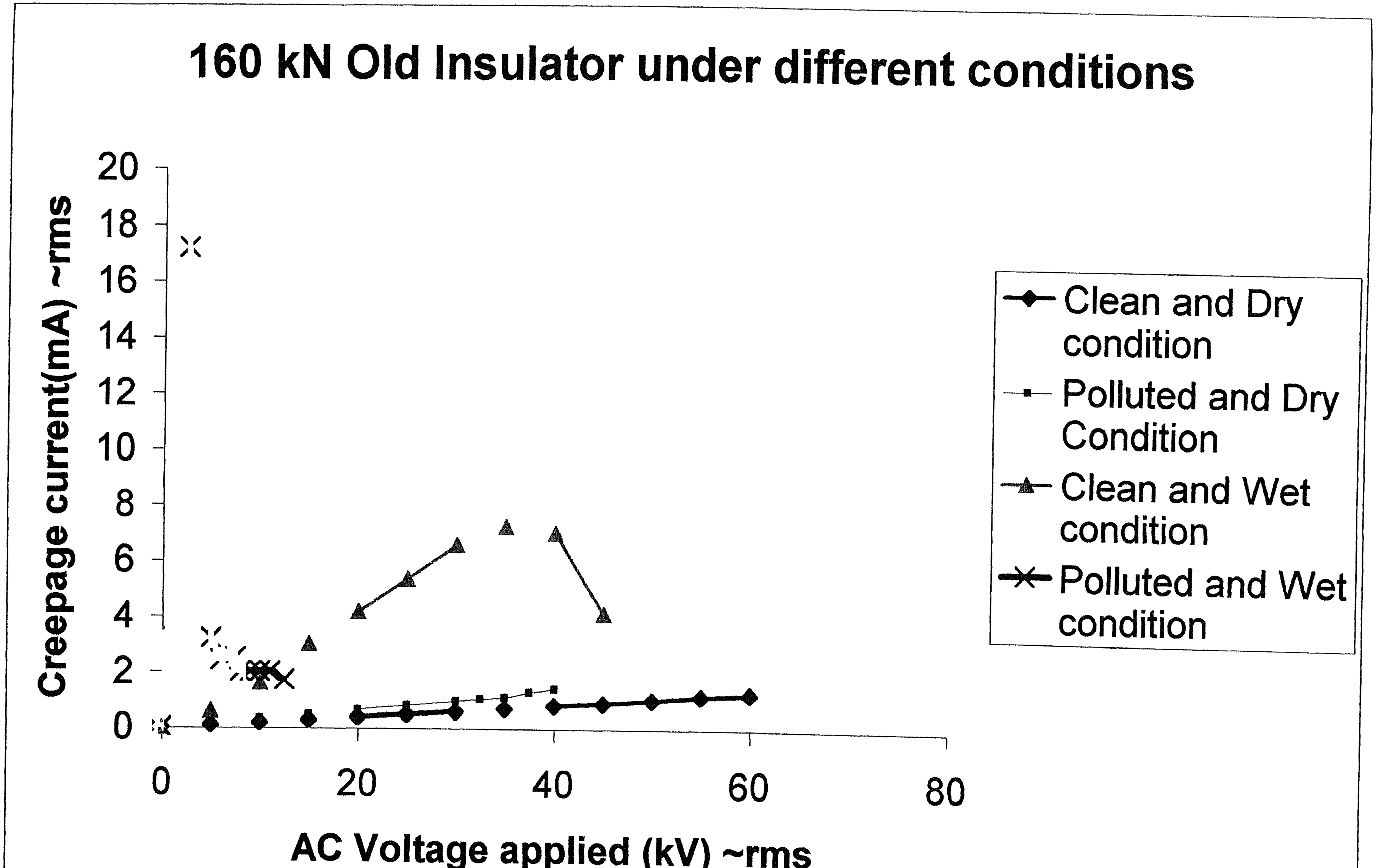

Polluted and wet condition
(120kN, New)
Creepage current(mA) ~ rms
35
30
25
20
15
10
5
0
Minimum Flashover
voltage 23 kV
0
5
10
15
20
25
AC Voltage applied (kV) ~ rms

Figure 8.16



160 kN Old Insulator under different conditions
Creepage current(mA) ~rms
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
AC Voltage applied (kV) ~rms
Clean and Dry condition
Polluted and Dry Condition
Clean and Wet condition
Polluted and Wet condition

Figure 8.17

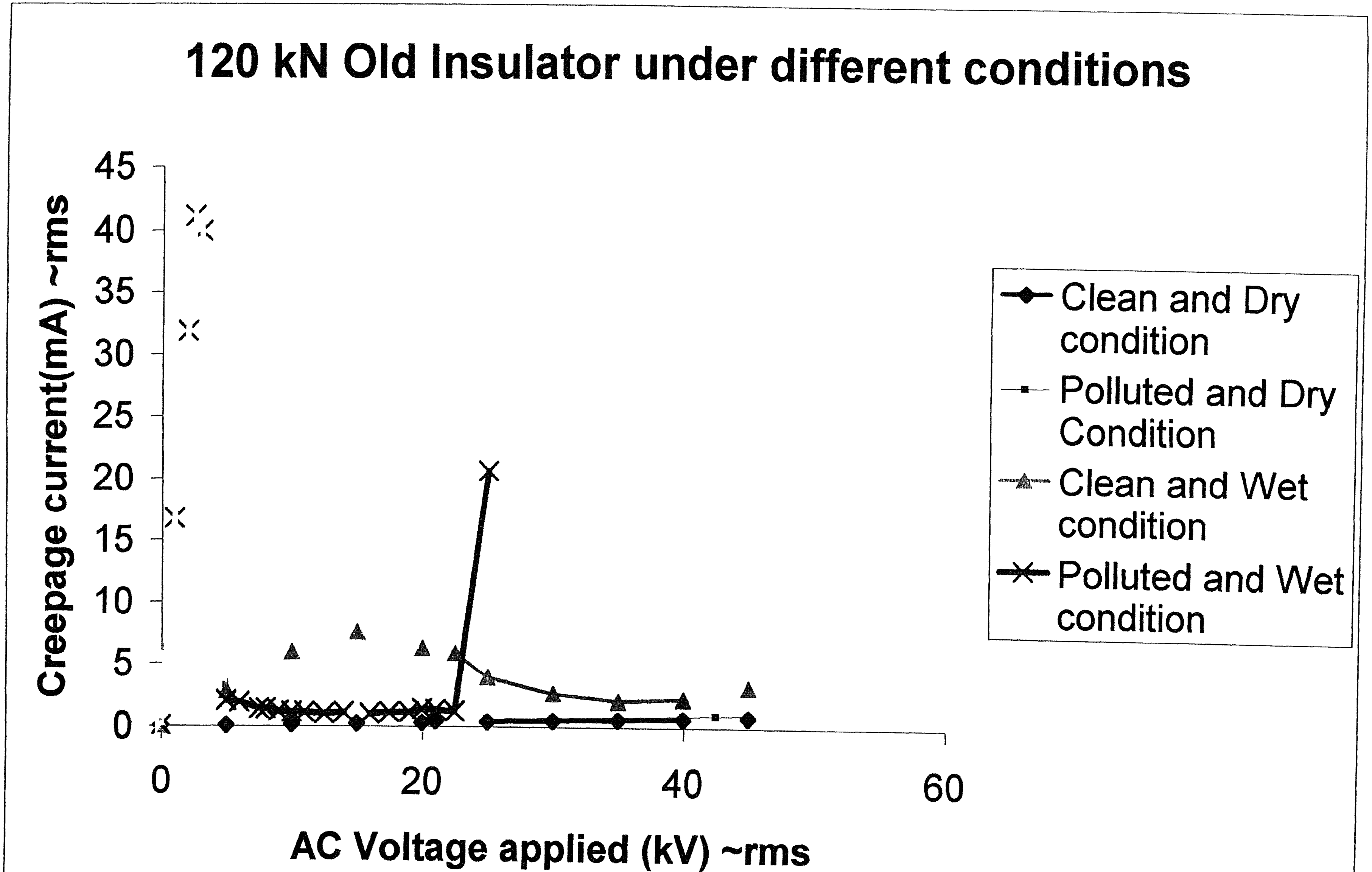

120 kN Old Insulator under different conditions
Creepage current(mA) ~rms
45
40
35
30
25
20
15
10
5
0
0
20
40
60
AC Voltage applied (kV) ~rms
Clean and Dry condition
Polluted and Dry Condition
Clean and Wet condition
Polluted and Wet condition

Figure 8.18

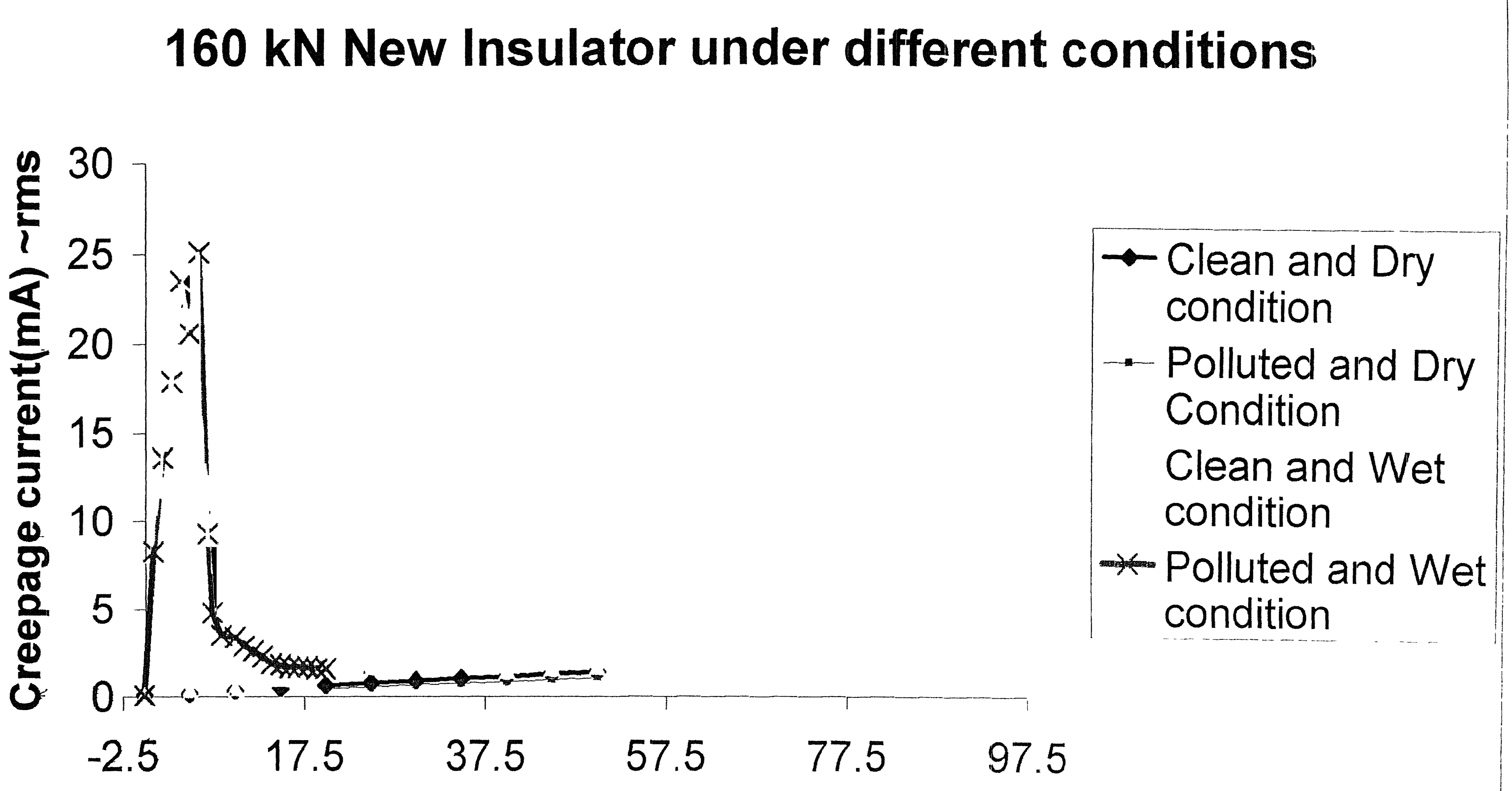
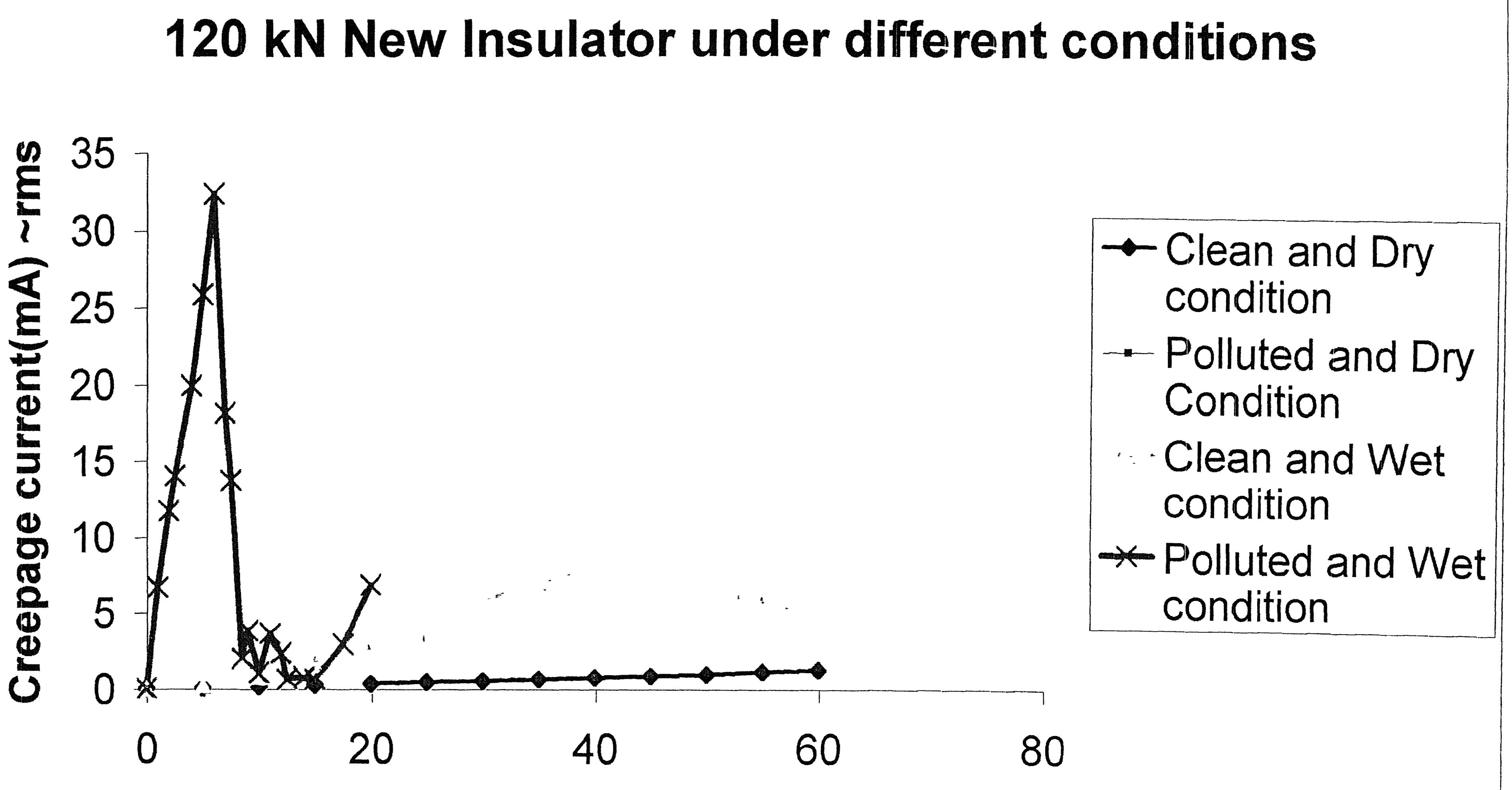
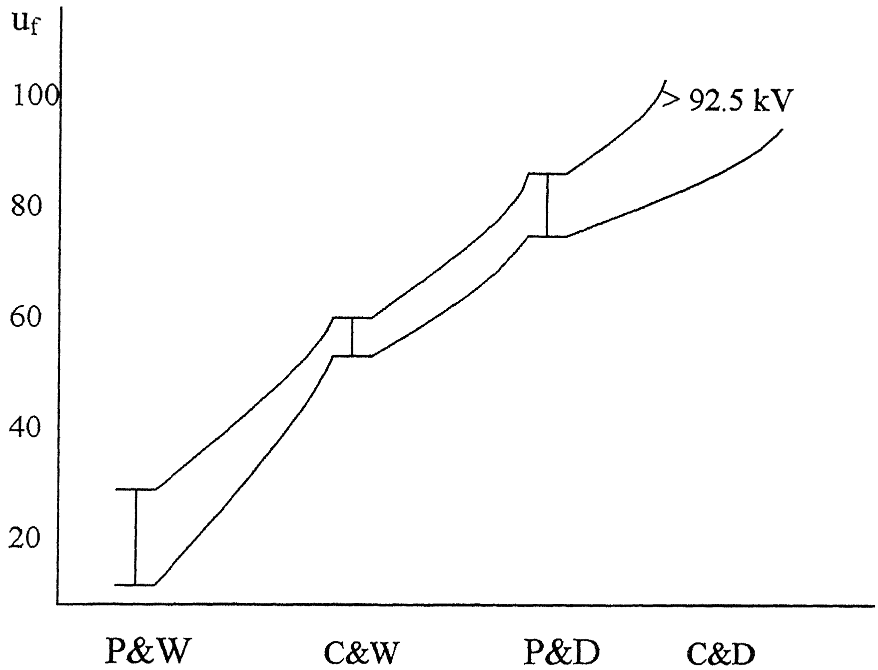

160 kN New Insulator under different conditions
Creepage current(mA) ~rms
30
25
20
15
10
5
0
-2.5
17.5
37.5
57.5
77.5
97.5
AC Voltage applied (kV) ~rms
Clean and Dry condition
Polluted and Dry Condition
Clean and Wet condition
Polluted and Wet condition

Figure 8.19


120 kN New Insulator under different conditions
Creepage current(mA) ~rms
35
30
25
20
15
10
5
0
0
20
40
60
80
AC Voltage applied (kV) ~rms
Clean and Dry condition
Polluted and Dry Condition
Clean and Wet condition
Polluted and Wet condition
Figure 8.20

160kN, OLD Insulator



Flashover voltage of Insulators under different conditions

Figure 8.21

U_f – AC Flashover voltage (kV) ~ rms

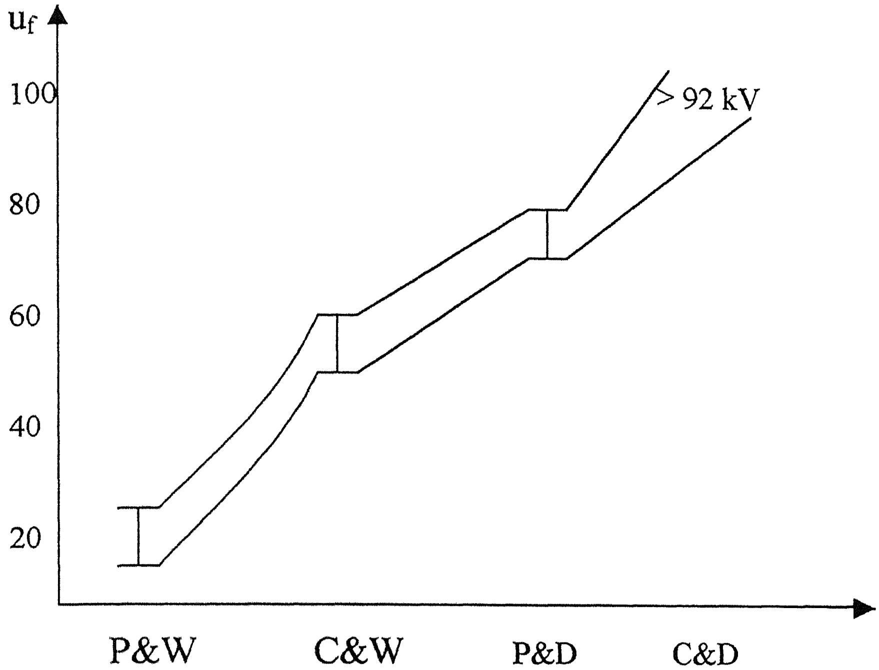
P&W – polluted and wet condition

P&D - polluted and dry condition

C&W – clean and wet condition

C&D - clean and dry condition

120kN, OLD Insulator



Flashover voltage of Insulators under different conditions

Figure 8.22

U_f – AC Flashover voltage (kV) ~ rms

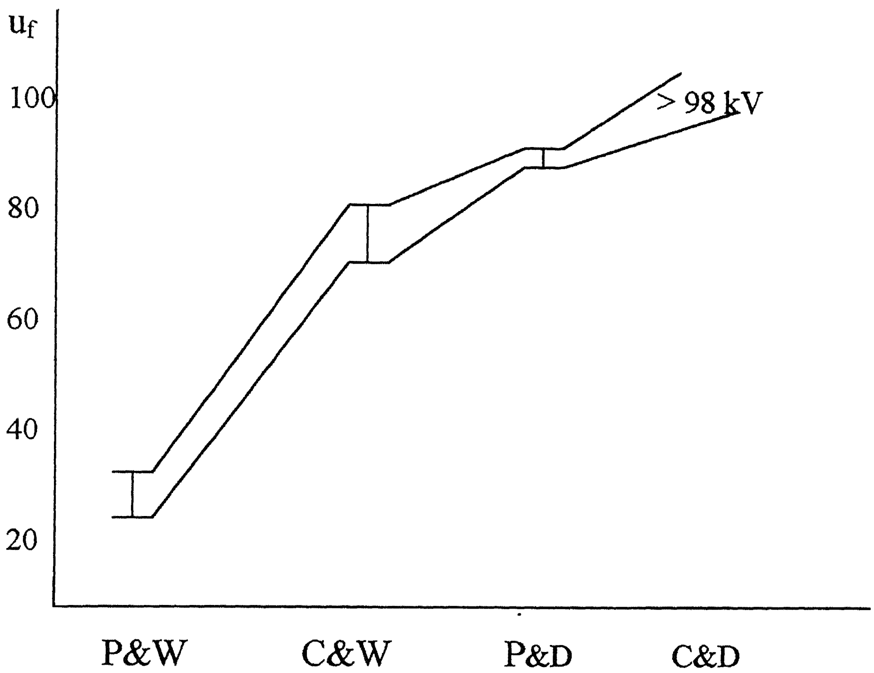
P&W – polluted and wet condition

P&D - polluted and dry condition

C&W – clean and wet condition

C&D - clean and dry condition

160kN, NEW Insulator



Flashover voltage of Insulators under different conditions

Figure 8.23

U_f – AC flashover voltage (kV) ~ rms

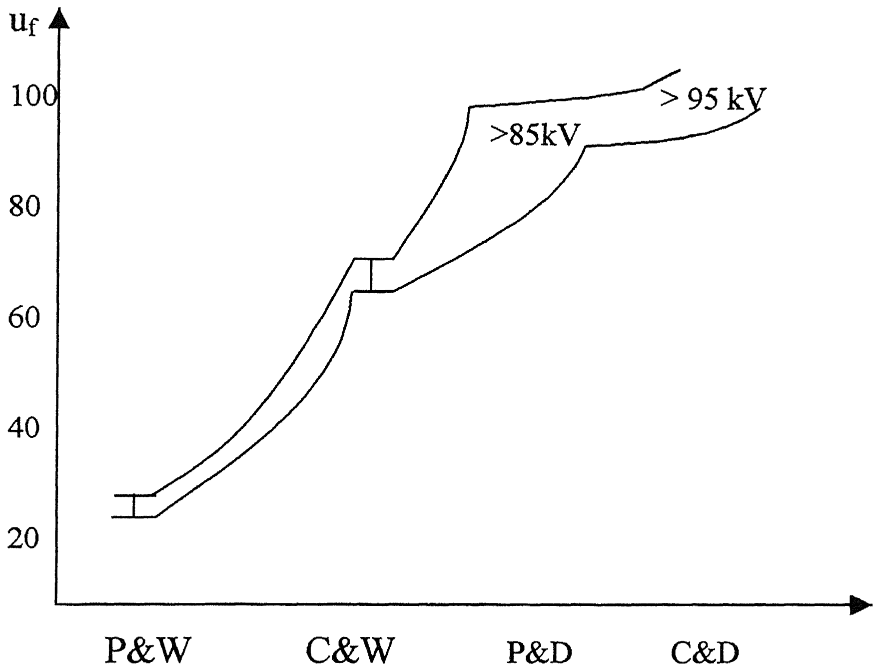
P&W – polluted and wet condition

P&D - polluted and dry condition

C&W – clean and wet condition

C&D - clean and dry condition

120kN, NEW Insulator



Flashover voltage of Insulators under different conditions

Figure 8.24

U_f – AC Flashover voltage (kV) ~ rms

P&W – polluted and wet condition

P&D - polluted and dry condition

C&W – clean and wet condition

C&D - clean and dry condition

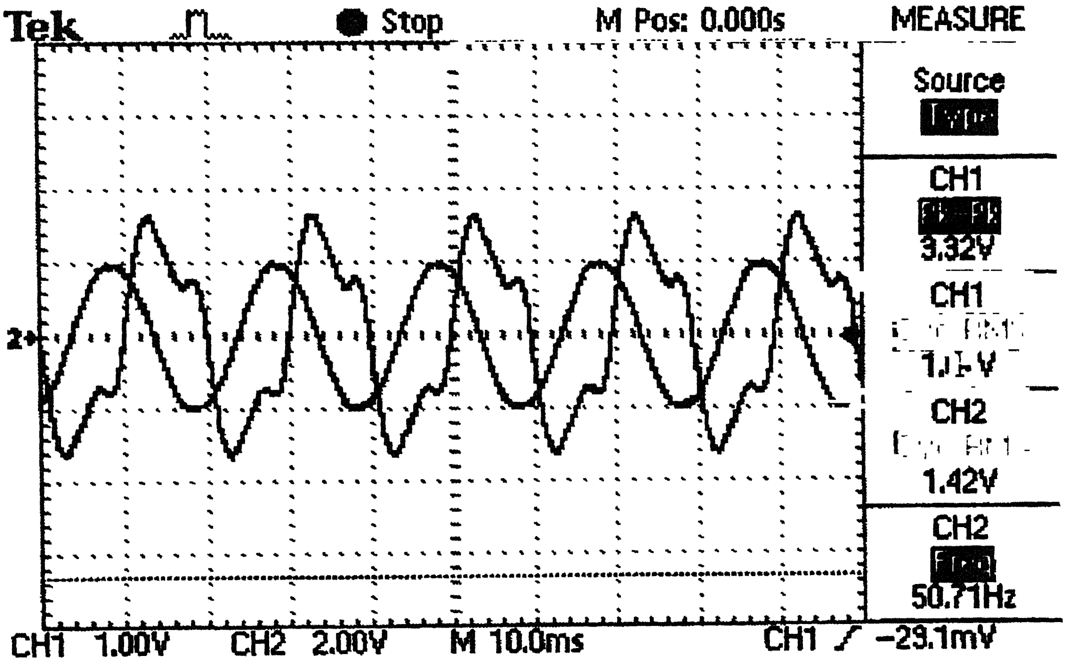


Figure 8.21 Creapage current waveform at 10 kV under clean and dry condition

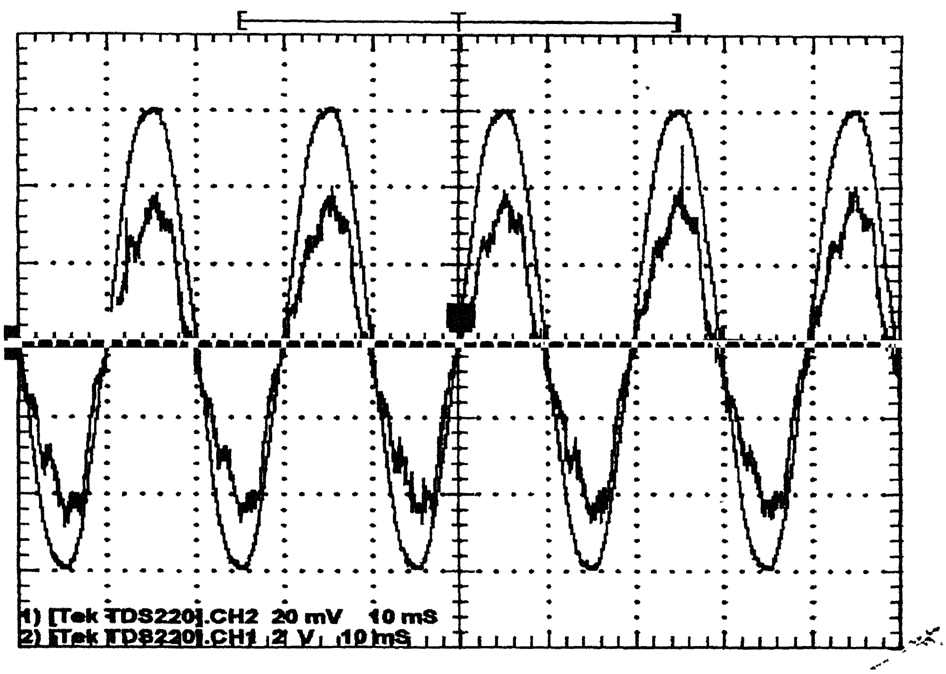


Figure 8.22 Creapage current waveform at 32 kV under clean and dry condition

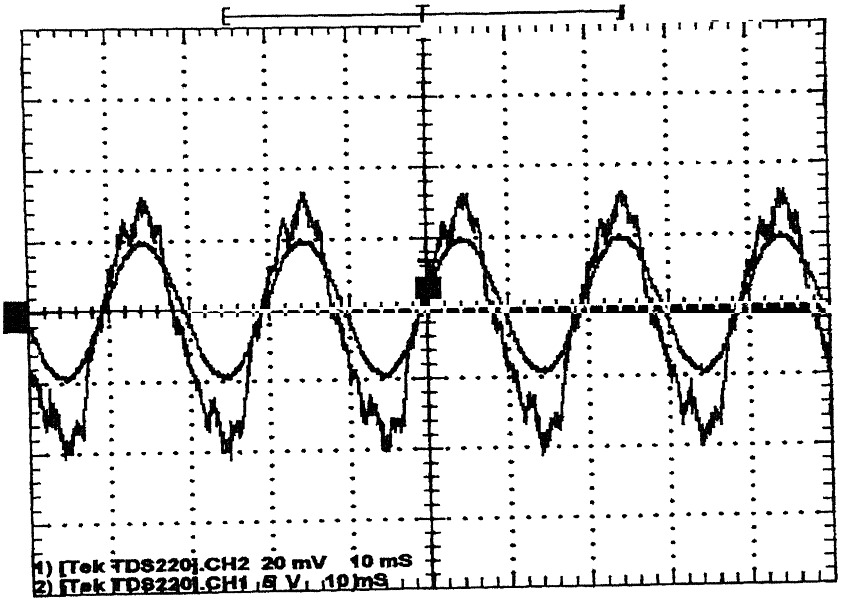


Figure 8.23 Creapage current waveform at 25 kV under Clean and wet condition

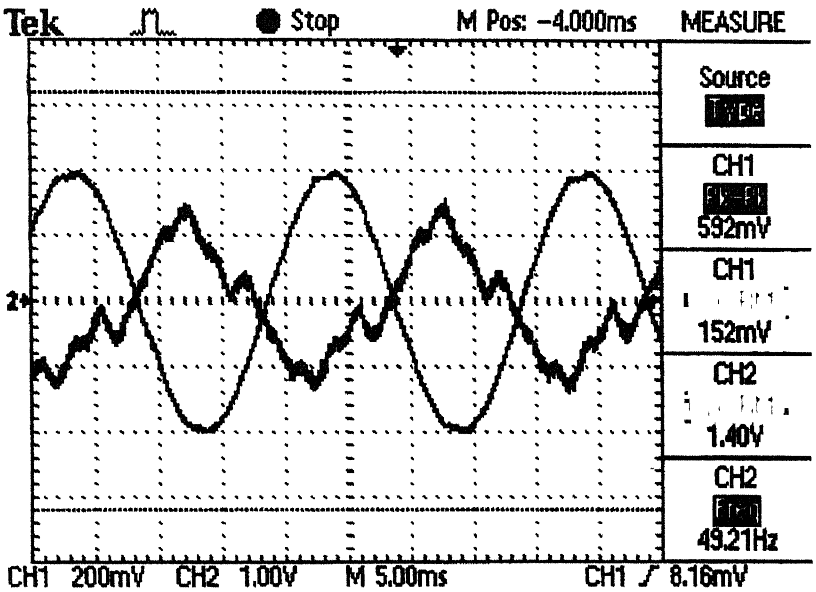


Figure 8.24 Creapage current waveform at 10 kV under Polluted and dry condition

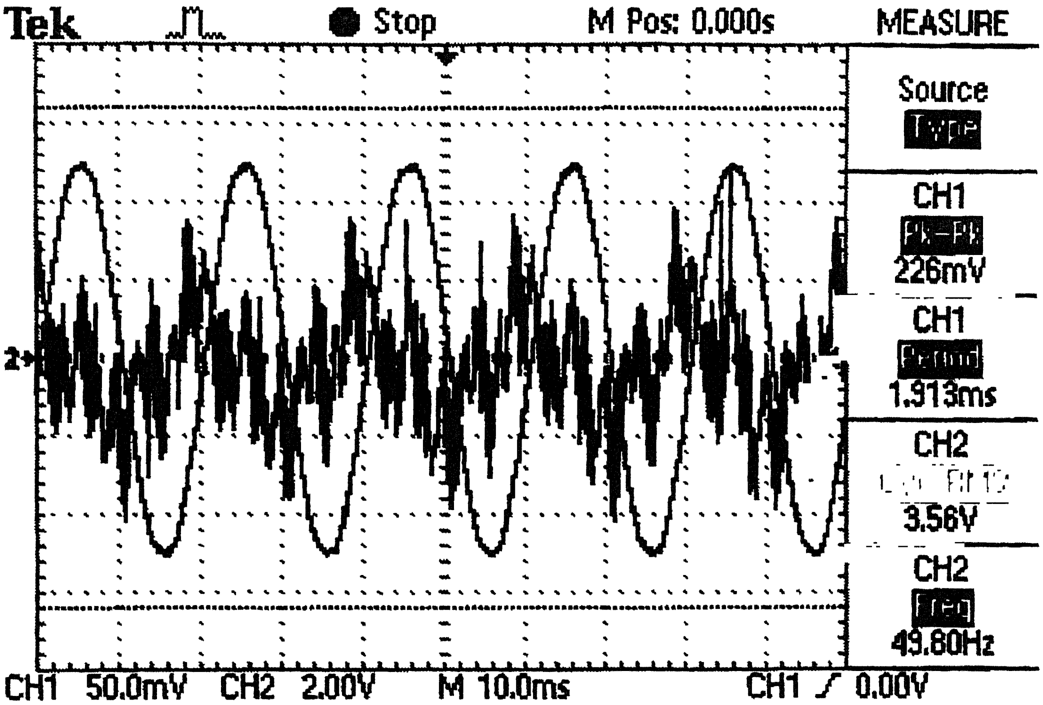


Figure 8.25 Creapage current waveform at 28 kV under Polluted and dry condition

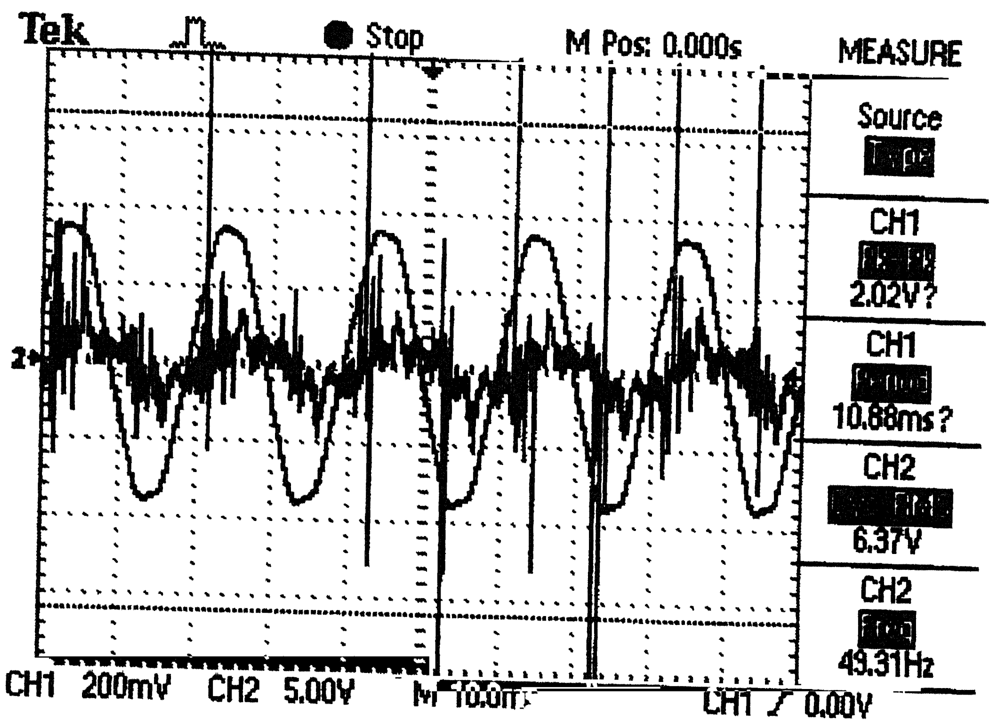


Figure 8.26 Creapage current waveform at 48 kV under Polluted and dry condition

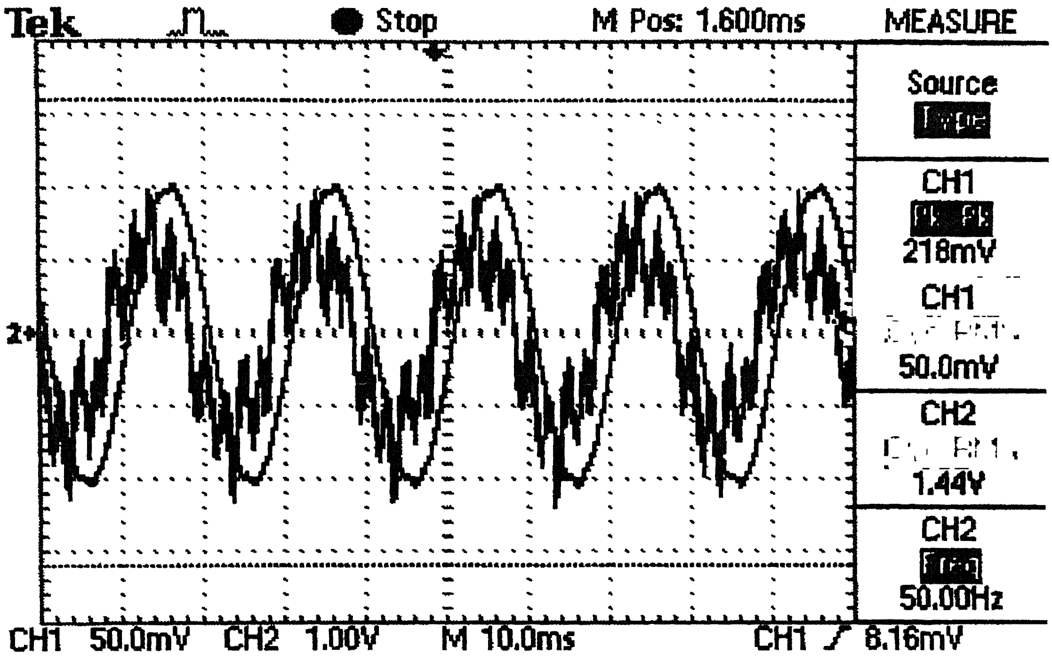


Figure 8.27 Creapage current waveform at 10 kV under Polluted and wet condition

Chapter 9

Performance of composite insulators under polluted conditions

Typical materials for composite insulators are:

- Silicon rubber (SR)
- EPDM/ alloys
- Polyolefins
- Epoxyresin

Among the materials SR has proven itself for decades to have excellent properties such as·

1. Hydrophobicity
2. Neglectable aging
3. No cleaning necessary

9.1 BENEFITS OF THE MATERIAL SILICONE RUBBER

Under normal pollution conditions, outdoor insulators accumulate pollution layer on their surface Depending upon the location of installation, the contamination layer may contain a high or low amount of soluble salts. Especially in coastal areas, the content of soluble salts can be relatively high. Under the influence of humidity, e.g. heavy fog can lead to wetting of the contamination layer, subsequently resulting in a solution of the salt particles included therein. The surface conductivity increases and significant surface leakage current begins to flow. Besides the loss of power, the current heats up the

deposited layer on the surface and incurs damage at the spot. As a result, dry band arcing takes place, which may lead, to flashover resulting into total insulation failure.[21]

9.2 Phenomena of Hydrophobicity

When water is sprayed on a clean hydrophobic surface, it creates distinct water droplets rather than wetting the surface. If a droplet on the surface reaches a critical size, it is usually removed by the force of gravity or exposure to wind.

When investigating different polymeric materials such as EPDM (Ethylene Propylene Diene Monomer), PTFE (Polytetrafluorethylen), epoxy resin or silicone rubber, it reveals that all these materials show to certain extent water- repellent properties when they are new. Of all these materials, however, silicone rubber has proven itself to be outstanding as it is the only polymer able to retain its inherent hydrophobicity during the entire lifetime of the insulator even under severe contamination conditions[20].

Silicones consist of inorganic system of alternating silicone and oxygen atoms. The combination of silicone and oxygen is a very strong bond and produces excellent mechanical and thermal stability in the material as well as high resistance to aging and UV-radiation. Attached to the silicone atoms there are hydrocarbon groups (CH3) responsible for the hydrophobicity of the material.

It has been discovered by tests that silicone rubbers play a special role among polymers. Test results have shown that silicone rubbers maintain their long-term hydrophobicity by continuous evaporation of low molecular components from the silicon bulk material.

Once the silicone rubber accumulates pollution, the low molecular silicones are able to penetrate the pollution layer and transfer the hydrophobicity to the layer itself. By covering the pollution particles with silicone, silicone rubber is actually able to influence a pollution layer.

The time required to transfer the hydrophobicity to the pollution layer depends upon several factors like layer thickness, thickness of the bulk material, temperature, the silicone rubber type used and so forth. Test results show, however, that even thick layers become hydrophobic after some days or time.

It is apprehended that the continuous flow of low molecular particles could lead to a loss in the amount of material. However, the tests have shown that the transfer of hydrophobicity requires only negligible amounts of material.

Resulting from excessive partial surface discharges, siliconised surfaces may temporarily loose their hydrophobic properties. It will then take some time (depending upon the production rate of low molecular silicones) till the material surface is able to built up its hydrophobicity again. This necessary recovery time has to be monitored when silicone rubbers are being tested in accelerated aging/pollution tests

It was observed that even after 5000 hours of alternating rain precipitation, salt fog and UV- radiation, the silicone still retains 50% of its water-repellent properties, whereas EPDM loses these properties almost completely It has been further shown that the hydrophobicity effect can be restored to its original state by drying the silicone for several hours.[21]

9.3 Environmental resistance[21]

UV-radiation from sunshine, chemical components in industrial gases, fumes from chimneys and salty environments in coastal areas are elements, which stress materials. Due to the inorganic nature of the molecular backbone chain, high temperature vulcanised (HTV) silicone rubber has proved to be superior in physical properties compared to other materials. The high UV-resistance results from its UV-radiation absorption characteristic, which allows only a small amount of the UV-radiation to affect the HTV silicone rubber. The molecular structure results in equal physical properties over a wide temperature range from approximately -50 up to +180 °C. Due to the nature of this structure, a high resistance to chemicals from chimneys, salt from coastal environments and ozone is provided. In addition, HTV silicone rubber gives a high degree of mechanical strength due to the greater length of their base polymer chains.

9.4 Experience with composite insulators

In countries like India, composite insulators are not in use, only conventional insulators like ceramic and glass (toughened) are used. But countries in North America, Europe and Japan are using composite insulators for nearly 3 decades. As a result, utility personnel around the world are eager for information regarding material types, design

configurations and specifications, testing, applications and operating experiences. Such information especially about silicone rubber insulators is in great demand.

In 1989, the IEEE published a survey on the experiences of U.S. utilities using composite insulators (H. M. Schneider et al., Nonceramic Insulators for Transmission Lines. IEEE Paper 89 WM 118-1 PWRD.). The survey covered 60 utilities. Service experience with 72,000 composite insulators installed in networks with voltages mainly higher than 100 kV was presented. A similar survey was published a year later by CIGRE (WG22 CIGRE, World Service Experience with HV Composite Insulators. ELECTRA No. 130, May 1990.)

Surveys, such as those listed above, are valuable for utilities that are considering introduction of composite insulators in their systems or expanding their current use. Up-to-date information is needed because of the variety of fabrication technologies and chemical compositions that evolve from year to year.[21]

9.4.1 Israel case

Presents survey over the past seven years, Israel Electric has installed approximately 4500 composite insulators throughout its system. Most insulators are of EPDM composition and are installed on medium-voltage lines. Composite insulators were chosen for their superior performance in combating pollutants, limited maintenance characteristics and resistance to vandalism.

In December 1993, the Electrical R&D Laboratory of Israel Electric conducted its own survey on utilities' experience with composite insulators. The goal of the survey was to gather information about service experience with silicone rubber insulators used in subtropical climate countries or in areas with industrial pollution problems. Since Israel electric had limited experience with silicone rubber insulators, the information gathered was to be used as the basis for future decisions on extending the use of these types of insulators throughout their network.

Sixteen utilities participated in the survey, representing approximately 60,000 composite insulators mainly consisting of silicone rubber composition. Utilities from South Africa (3), Canada (3), Australia, Namibia, Spain, Switzerland and the U.S. (6) responded to the questionnaire. Supporting statements characterized the benefits of using composite insulators over traditional ceramic units. Following comments were included:

Some utilities from the U.S. and Namibia decided to replace ceramic insulators with silicone rubber insulators to reduce maintenance expenses.

One utility reported that silicone rubber insulators were installed mainly to combat vandalism problems; however, the reduction in construction and maintenance expenses was also considered.

Utilities using both silicone rubber and EPDM composite insulators in Australia and Canada reported that silicone rubber insulators were preferred in heavy pollution environments.

One utility said that the initial low purchase cost of silicone rubber insulators for high-voltage lines provided adequate justification for purchase without considering other supplementary benefits, such as operation and maintenance expenses.

Some of the larger utilities with extensive experience with composite insulators have changed their design and purchasing specifications to accept only silicone rubber insulators.

Although most silicone rubber insulators go unwashed in heavily polluted operating environments, few flashovers were recorded. This statement supports experimental results that prove the superiority of silicone rubber materials over EPDM and porcelain after aging and pollution accumulation. Almost every utility reported that they have suspended maintenance activities (i.e. live-line washing) on lines equipped with silicone rubber insulators. This suspension could translate into 10 years or more of no maintenance.

Few mechanical failures were reported. In all reported cases the failures were classified as brittle fracture-type failures that occurred on units with E-type fiberglass design, which are no longer being manufactured.

The majority of the utilities surveyed decided to use silicone rubber insulators on their high-voltage lines because of their lower acquisition and maintenance costs. Life cycle cost calculations performed at Israel Electric has proven that it is economically profitable to use silicone rubber insulators on medium-voltage lines also.

The information gathered in this survey represents the past 10-14 years of actual field experience with silicone rubber insulators. Their data confirms reports from insulator manufacturers that composite insulator use among utilities continues to rise. A moderate initial purchase cost, superior operating performance characteristics and

reduced maintenance requirements assures that silicone rubber insulators will remain an economically viable option on newly constructed lines and for re-insulation projects.[11]

9.4.2 Srilanka case (Performance of Non-ceramic Insulators in Tropical Environments)

Six different types of 33 kV insulators (silicone rubber, EPDM, RTV coated porcelain and porcelain) were installed at three different sites exposed to marine, industrial and clean environments in Sri Lanka. The insulator performance was periodically tested by visual scrutiny, hydrophobic classification and pollution severity measurements for more than three and half years. The silicone rubber insulators and RTV coatings, in general, preserved hydrophobicity, whereas the EPDM insulators showed distinct surface changes. Porcelain insulators flashed over on several occasions. Algae growths were found on silicone rubber surfaces but their effects on insulator performance were not strong.

9.4.3 Service experience of European, American, Asian African and Australian test stations

In this research work by A.J. Maxwell, E. Gnandt and R. Harting of STRI, Sweden data has been collected using a standardised guide which was distributed to participating utilities. This guide ensured compatibility between data obtained from different sources. Instructions were given for how to perform visual inspections and hydrophobicity measurements. Photographs of different types of damage and deterioration of surfaces with varying hydrophobicity were provided in order to assist the participants. High data quality and compatibility was this assured.[9]

The presented data was collected between 1994 and 1998 from 275 composite insulators from 23 manufacturers and 36 utilities from Europe, North and Central America, Asia, Australia, and Africa. The climate types varied from arctic conditions in northern Europe with 9 months of winter weather, to tropical climates in Central and North America with temperatures continually over 20° C. The environments vary from the clean air of northern Scandinavia to extreme coastal environments bordering the ocean and exposed

to direct salty sea spray, as well as areas with heavy industrial pollution in former Soviet republics

For each insulator, in-depth information regarding the environmental and climatic conditions could be obtained; parameters include maximum, minimum, and average temperature, sunshine hours, rainfall, pollution level, climate type (i.e. arctic, temperate, etc.), environment type (i.e coastal, inland, etc.). In addition insulator design data such as creepage and arcing distances, material choice, presence of corona rings, manufacturer, insulator type (i.e. suspension, post, etc.), etc. were collected. Furthermore, the date of installation, as well as the system voltage level and voltage type (i e. AC/DC) was available for all insulators.

An analysis was carried out where the occurrence of different types of damage and deterioration and hydrophobicities has been compared to design, environmental, and climatic data. The concentration of material deterioration and damage in coastal environments could be clearly observed.

The main conclusions were as follows:

- For SIR insulators· only those installed in coastal environments with specific creepage distance shorter than used for ceramic insulators in the same areas exhibited material deterioration and damage e.g. erosion.
- Pollution in coastal areas reduced the hydrophobicity of SIR insulators within a few years. All SIR insulators installed in inland areas essentially remained hydrophobic after up to 12 years.
- EPDM insulators were affected by chalking and crazing in all environments, and even when a longer creepage distance was adopted than for ceramic insulators, Damage e.g. puncture has occurred in coastal areas. Virtually all EPDM insulators were hydrophilic.
- ESP insulators were found to behave in a similar manner like EPDM insulators as far as deterioration and hydrophobicity reduction are concerned.

Thus the Pollution environment and insulator design are more important factors than the number of years in service for determining the level of hydrophobicity reduction, deterioration, and damage.

9.4.4 Annerberg field station case

The long-term performance and the material state of polymeric insulators were examined from December 1987 to February 1997. To a large extent the study was conducted at Anneberg field station, on the West Coast of Sweden. The project comprised a great number of commercially available polymeric insulators from several prominent manufacturers. Each type of insulator was energized with high voltage alternating current (HVAC) as well as high voltage direct current (HVDC). In addition, out of each type of insulator, two samples were not energized: one was exposed to the environment only and one was stored indoors.

The silicone rubber (SR) insulators maintained a high degree of their initial hydrophobicity and with respect to leakage currents performed better than the porcelain insulators. The results obtained show that heavily stressed SR insulators with specific creepage distances of the order of 8.2 mm/kV to 9.3 mm/kV had leakage currents exceeding 80 mA during a salt-storm in January 1993. However, after that occasion they showed relatively low leakage currents indicating that the sir has the ability to recover its high surface resistivity and thus a good performance. The measurements indicate that, at light levels of pollution, it is possible to reduce the creepage distance of the SR insulators compared to that of a ceramic one.

Under severe field conditions the ethylene-propylene-diene monomer (EPDM) rubber insulators performed worse with respect to leakage currents and flashovers compared to the porcelain insulators with the same electric stress. Visual observations verified that the surfaces of most of the EPDM rubber insulators had eroded. The surface erosion included cracking and chalking due to environmental exposure and leakage current activity. The material aging of the EPDM rubber resulted in a degraded performance of the insulators under contaminated conditions. In sum, the results suggest that the application of the

EPDM rubber insulator for a higher electric stress compared to that prescribed for the ceramic one is not advisable.

9.4 5 China case

In order to decrease the leakage currents and increase the flashover voltages of ceramic and glass insulators, especially under severe contamination, the following methods have been used in china:

- While designing the size and profile of the insulator to increase the creepage path, keep a large area of insulator dry for a longer time during natural wetting. Also minimize the accumulation of contamination on the insulator surface using aerodynamic principles.
- Coating insulators with water repellant materials having low free 2surface energies, such as grease or room temperature vulcanized (RTV), silicon rubber to prevent water filming on the insulator surface.
- Attaching composite polymer skirts around the insulator edge as sheds to increase the creepage path.

The first method is effective under clean condition, but has not been successful under condition of severe contamination. The second method requires regular re-application of grease or RTV, in most cases every six years; this is labour intensive and expensive especially if done under hot line conditions to avoid service interruption. The third method is successful, but only in short term because of the poor bonding between the polymer skirts and the porcelain surface.[7]

Chapter 10

Remedies of flashover

Remedies are called for, evidently, when the flashover frequency rises above acceptable level What is acceptable depends upon the importance of the line or substation and on the required quality of supply, in terms of outage time per year. Flashovers in substations often had serious consequences, and lower than one per year per station would normally be called for.

The causes of flashover are part systematic and part random. An insulator will carry a resident layer of contamination, accumulated since its in service last cleaning operation, which may fluctuate as the resultant of depositing and purging events, but still it remains quasi- stable. The insulator is also challenged by random occurrences like condensation, frost and onshore gales. These add water, ionisable material or both, which, depending upon the design of insulator, either may or may not carry the surface conductivity into a range where flashover can take place.

Remedies are therefore essential either because the resident layer is dangerously high in terms of salt density, causing frequent flashover under the normal low-level challenges, or because the challenges are more severe or more frequent than assumed originally. Too high a resident layer can arise either from misjudgment of the local severity or wrong choice of insulator. not uncommonly the severity is altered by the actual installation of the electric supply system, triggered by industrial development causing pollution. Power systems are never designed keeping improbable conditions in mind. A system which is efficiently designed to handle one bad condition like fog may fail if two adverse conditions simultaneously act. For example neither fog nor drought alone can cause flashover; their combination is clearly highly improbable. But if they occur together it can lead to flashover.

Wide difference thus arise in the type of remedy which is needed, depending upon what is causing the flashover and what are the relative costs of outage and remedy.
The probable remedies for flashover affecting lines include the installation of more or better insulators, the adoption of V or X sets, the fitting of devices to handle creepage path or the use of resistive glaze. Palliatives could include greasing or live washing.

10.1 Optimised insulator shapes and creepage paths

Improvements which follow increase in length of insulator, increase in creepage-path length, inclination from vertical and replacement of long rods or line posts by cap and pin strings to allow assessment of their relative values are permanent remedies for flashover.

Reduction of surface gradient is by far the best step to take, as a remedy, provided it can be done without serious side effects. It is worth repeating that some 10% decrease in surface gradient is as effective as halving of surface conductivity, in general
A new design of cap and pin insulator is suggested by Li Xiaofeng and his group in paper "A novel method for improving the performance of polluted insulators" [7] in which an annular metal sheet coated with silicon rubber is added near to the base of the cap of a conventional insulator to improve its performance under both clean and polluted conditions. The annular metal sheet is electrically connected to the insulator cap, rendering the electric field distribution more uniform, and therefore increasing the corona Inception voltage; it also makes the electric field direction approximately perpendicular to the surface of ceramic insulator, rather than approximately parallel, as on the conventional insulator without the annular sheet This also tends to reduce the leakage currents and increase the flashover voltages.

The upper surface of the annular metal sheet also collects much of the contamination which would otherwise be deposited on the insulator upper surface. This again increases the flashover voltage and decreases the surface leakage current of insulator under polluted case.

10.2 Insulator washing / cleaning

The principle of washing, on line or on shut down, is basically to reduce the surface resident layer without provoking flashover either of the insulator which is being washed or in its neighborhood or over In case of off time washing, the risk may arise from overspray of polluted water onto adjacent live insulator· this must be taken into consideration when high washing pressures are used.

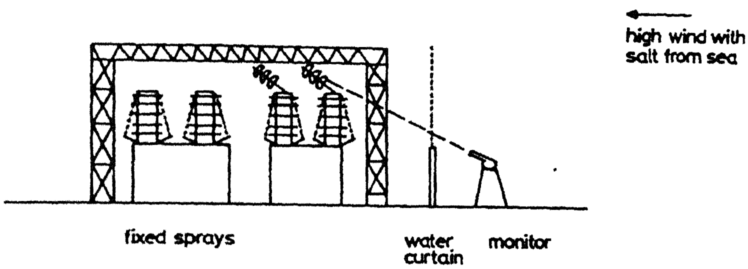


Fig 10.1 Live washing

Water curtain intercepts and dilutes wind- borne salt, in typhoon conditions

Sprays and monitors are provided for ground – mounted and aerial insulators

Water jet washing is effective in removing solid pollution layer and is appropriate to adhesive deposits. Spray washing, on the other hand, uses greater quantity of water but is more efficient than jet for removing soluble material Mobile washing equipment is confined to the water jet system in general, although mobile water tanks are occasionally “plugged into” permanent spray nozzles.

Automatic spray washing systems are used in many substations, which are subjected to coastal pollution.

Typical equipment comprises a 5000 litre tank, pump, hoses; nozzles and access boom, all mounted on a vehicle. Pumping pressure range from 14 to 40kg/cm^{2,} with nozzle pressures somewhat lower. Flow rates are of the order of 100 litres/min. To reduce the hazard of current leakage along the jet, common practice is to use an automatic

interrupting system, which delivers a series of discontinuous or broken jet of water. A minimum value of water resistivity is usually specified, greater than 10,000Ωcm, with the intention of reducing the risk of flashover at the washed insulator[3].

Clearances from nozzle to live metallic parts range from 6m at 275kV to more than 60m at 765kV. At such long distances the water jet is likely to get disturbed by wind. Fixed nozzle system requires remote aiming and position monitoring equipment. In all cases the insulator string or post insulator is washed from top to bottom, in order to minimise the risk of cascading effect due to polluted wash water.

Although washing is effective in removing pollution, the total operation, especially for a large substation installation, has many disadvantages as well as high capital and running costs. The mechanical fault rate of the washing plant tends to exceed the electrical fault rate of the insulators: there will be thousand of nozzles, kilometers of pipe work, dozens of valves, all subject to corrosion and statistical malfunction. Pump and water-processing plants need regular maintenance and replacement. Less obvious is the change in local microclimate, leading in some cases to much enhanced humidity induced failure rates in other pieces of equipment than the insulator and washing gear.

10.3 Surface Treatments

Many kind of surface treatment, with oils, greases and pastes, are applied since, Invariably with some degree of success but usually these pose disadvantages, especially in the form of damage to the substrate.

Such coatings act to prevent flashover in two separate ways, firstly in reducing the tendency for water drops to coalesce into a continuos film and secondly in encapsulating the particles of solid pollution, thus preventing their going into solution form and in increasing the surface conductivity. Both the principle classes of coatings, silicon pastes and petroleum gels or hydrocarbon greases, have been extensively used and their properties compared[3].

Silicon pastes are mixture of silicon oils and powders, usually silica flour or similar inert minerals with large surface area. They are soft and easy to apply, and are not

subjected to movement in hot climate since their viscosity are remain constant from –50^{0}C to +200^{0}C.

When in good condition, silicon pastes are highly effective. Petroleum gels basically contain hydrocarbon waxes and oils, but some also contain contain polymers or other large molecules. The purpose of these polymers is to reduce the variation of viscosity with temperature. They act differently from the silicones, not smothering so rapidly because they have less mobile content. When discharges or heavy sparking occurs they melt locally, encapsulating the dirt and presenting a fresh surface, which is non- wetting

10.4 Hybrid insulators

Hybrid insulators have now been developed up to highest transmission voltages. Comprehensive tests have been performed on interfacial materials, Interesting differences have emerged between the behaviors of interfaces where the substrate is ceramic, as in the hybrid and where it is fibrous composite, as in the polymeric insulators. The hybrid interface is remarkably stable, even in the presence of artificial faults which causes the fibrous rod to fail rapidly at least in the case where the outside of the polymeric part is not heavily polluted. There are grounds for hope that interracial failures will not affect hybrids as they do polymeric insulators.

APPENDIX –A

Salient features of 400 kV line

1. Tower Data

(i) Normal design span	400 m
(ii) Wind span	400 m
(iii) Weight span	
(a) Minimum	320 m
(b) Maximum	480 m
(iv) Ground clearance	8.84 m
(v) Live metal clearance	
A. On suspension towers	
(a) For normal swing – 0^0 to 55^0	3 05 m
(b) For maximum swing – 25^0 to 45^0	1.83 m
B. On tension towers	
For jumper deflections From 0^0 to 20^0	3.05 m
(vi) No. of sub-conductors	Two per phase
(vii) Intra-group spacing	450 mm
(viii) Bundle arrangement	Horizontal

(ix)	Inter-phase spacing	11 m
(x)	Shielding angle (at tower)	25^0, improved to 10^0 for new lines.
(xi)	Midspan clearance	10.7 m, changed to 9.0 m for new lines

2. Conductor and Earthwire

(i)	Conductor	'Moose' ACSR (54/3.53 mm Al + 7/3.53 mm St.), copper equivalent area 325 sq. mm.
(ii)	Earthwire size	Two number galvanised steel 60-ton quality wire of size 7/3.66 mm.

3. Insulator data

(i)	Suspension string	23 discs of size 255x145mm of 120kN E & M strength.
(ii)	Tension string	2 x 22 discs of size 280 x 170 mm of 160 kN E & M strength.

APPENDIX - B

SURFACE GRADIENT CALCULATIONS FOR BUNDLE CONDUCTORS

Figure shows the circuit configuration of a 400 kV Transmission line with following line parameters·

a. Phase spacing (d) = 12 m
b. Sub-conductor spacing = 44 cm
c Height of conductor at support point (h) = 17 72 m
d. Phase conductor size – Moose overall diameter (2r) = 3.18 cm
e. No. of sub conductors in bundle (n) = 2

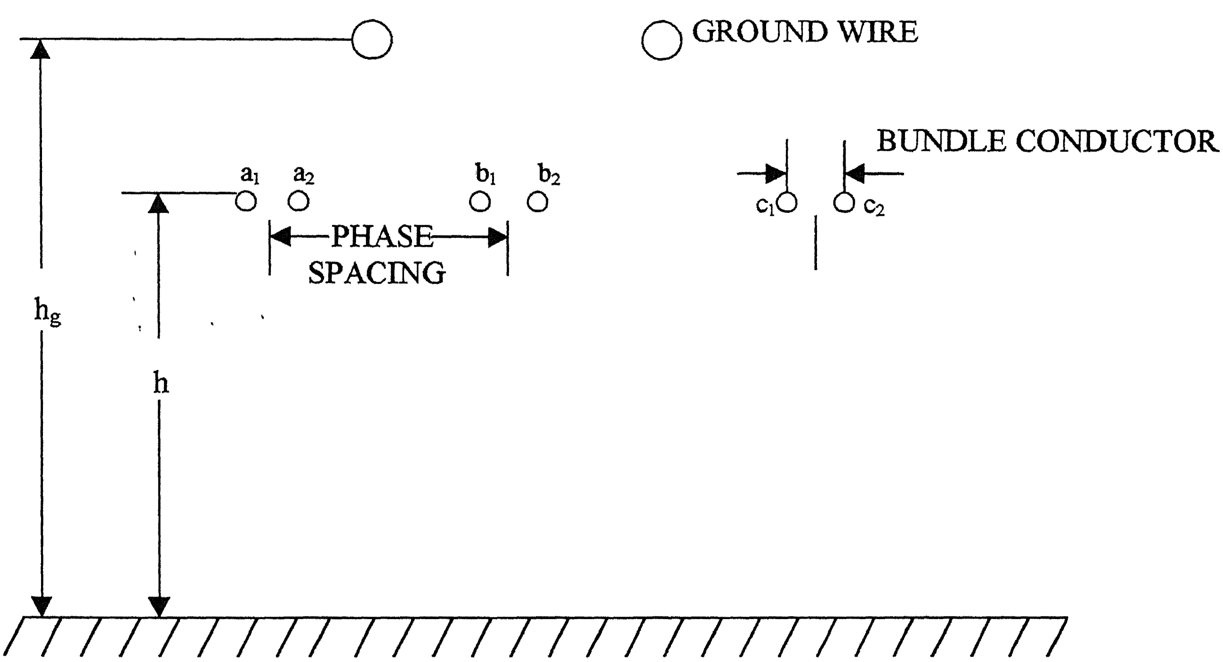


Figure B-1: Circuit configuration of a 400 kV transmission line

(ii) Equivalent radius (re) on calculations comes out to be 8.4 cm

(iii) Using Maxwell's co-efficient, the charges on three phases are given by (neglecting effect of ground wires):

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} P_{aa} & P_{ab} & P_{ac} \\ P_{ab} & P_{bb} & P_{bc} \\ P_{ac} & P_{bc} & P_{cc} \end{bmatrix} \begin{bmatrix} Q_a \\ Q_b \\ Q_c \end{bmatrix}$$

Where, $P_{aa} = 1/2\pi\epsilon_0 \, Log_e \, 2h/r_e$

$= 5.88/2\pi\epsilon_0$

$= P_{bb} = P_{cc}$ (due to horizontal configuration)

$P_{ab} = 1/2\pi\epsilon_0 \, Log_e \sqrt{(4h^2 + d^2) / d}$

$= 1/2\pi\epsilon_0$

$P_{ac} = 1/2\pi\epsilon_0 \, Log_e \sqrt{(h^2 + d^2) / d}$

$= 0.47/2\pi\epsilon_0$

The value of h has been taken as 15 m in calculations to include the effect of sag.

(d) Solving equations (1) for Q_a, Q_b and Q_c, we have

$Q_a = Q_c$

$$= V(P^2_{aa} - P^2_{ab})/ \Delta \left[1 + 0.5(P_{ab} + P_{ac})/(P_{aa} + P_{ab})\right]$$

$$Q_b = V(P^2_{aa} - P^2_{ac})/ \Delta \left[1 + P_{ab} /(P_{aa} + P_{ab})\right]$$

Where, V is the r.m s value of voltage across phase to ground, and

$$\Delta = \begin{vmatrix} P_{aa} & P_{ab} & P_{ac} \\ P_{ab} & P_{bb} & P_{bc} \\ P_{ac} & P_{bc} & P_{cc} \end{vmatrix}$$

$= 191.87/(2\pi\epsilon_0)^2$

(e) Putting the required values in equations (2) and (3) we get :

$Q_a = Q_c$

$= 2\pi\epsilon_0 \times 0.2 \times V$

$Q_b = 2\pi\epsilon_0 \times 0\ 208 \times V$

(f) The gradient of phases 'a', 'b', 'c' is $g_a = g_c$

$$= g_{av}\left(1 + \frac{2(n-1)\sin\pi/n}{d_s/r}\cos\theta\right)$$

$$= \frac{Q_a}{2\pi\epsilon_0 nr}\left(1 + \frac{2(n-1)\sin\pi/n}{d_s/r}\cos\theta\right)$$

$$= \frac{0.2XV}{2X1.59}\left[1 + \frac{2X1.59}{44}\cos\theta\right]$$

$$= 14.52 + 1.05\cos\theta$$

Similiarly, $$g_b = \frac{Q_a}{2\pi\epsilon_0 nr}\left[1 + \frac{2(n-1)\sin\pi/n}{d_s/r}\cos\theta\right]$$

$$= \frac{0.2XV}{2X1.59}\left[1 + \frac{2X1.59}{44}\cos\theta\right]$$

$$= 15.1 + 1.1\cos\theta$$

APPENDIX- C

Number of insulator units indicated for satisfactory operation in different contaminated condition

(All strings in vertical position)

Class of contamination	345 kV		500kV	
	Standard	Fog type	Standard	Fog type
(A) Clean atmosphere. Rural & Forest region. No Industrial contamination	Insulation not chosen by contamination requirement			
(B) Slight atmospheric contamination. Suburbs of large industrial area.	18	13	25	19
(C) Heavy contamination, Containing soluble salts Up to 5 furnaces, dust Metallurgical and chemical works.	22	17	32	25
(D) Very heavy contamination containing 15 percent or more soluble salts, dust from aluminium and chemical works.	27	22	42	31
(E) Salt precipitation, sea-side Region, salt marsh, steppe.	35	27	50	39

APPENDIX-D

Potential distribution over a string of suspension insulator

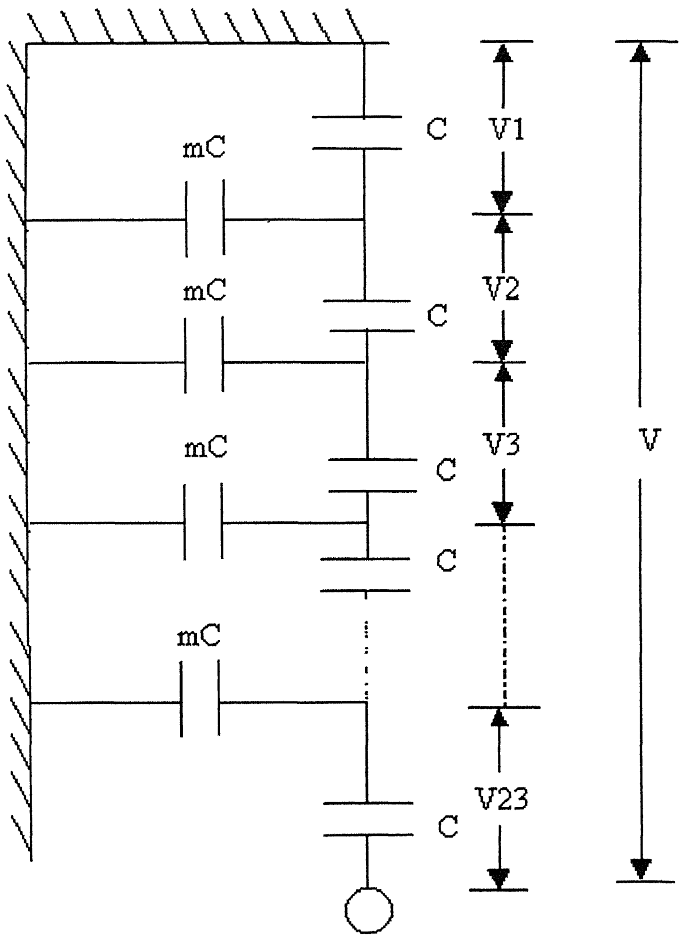


Fig D1 Potential distribution across a string of twenty three insulators

Let V be the operating voltage (line to ground) and V_1, V_2, V_3, ---, V23 the voltage drop across the units

$$V = V_1+V_2+ V_3 +---+ V_{23}$$

From Fig., we can write

$\omega mC\ V_2 = \omega mCV_1 + \omega CV_1$ (ω = supply angular frequency)

$V_2 = V_1\ (1 + 1/m)$

Taking m= 8

$V_2 = V_1\ (1+ 1/m) = 1\ 125\ V_1$

Similarly calculating other voltages

$V_3 = 1.390625\ V_1$, $V_4 = 1\ 7\ V_1$, $V_5 = 2\ 092\ V_1$, $V_6 = 2.566\ V_1$, $V_7 = 3\ 1482\ V_1$

$V_8 = 3.86\ V_1$, $V_9 = 4.7388\ V_1$, $V_{10} = 5.18\ V_1$, $V_{11} = 7.13\ V_1$, $V_{12} = 8.67\ V_1$

$V_{13} = 10.645\ V_1$, $V_{14} = 13.06\ V_1$, $V_{15} = 16.02\ V_1$, $V_{16} = 19.65\ V_1$, $V_{17} = 24.117\ V_1$,

$V_{18} = 29.588\ V_1$, $V_{19} = 36.3\ V_1$, $V_{20} = 44.533\ V_1$, $V_{21} = 54.64\ V_1$, $V_{22} = 67.04\ V_1$,

$V_{23} = 82.25\ V_1$

Now line to line voltage is 400 kV

Per phase voltage = $400/\sqrt{3} = 231$ kV

$V = V_1 + 1.125\ V_1 + 1.390625\ V_1 + \ldots\ldots + 82.25\ V_1$

$= 438.32\ V_1$

$V_1 = 231/ 438.32$

$= 0.527$ kV

voltage across the insulator nearest to conductor = 82.25 X 0.527 = 43.337 kV

APPENDIX -E

TESTS AND STANDARDS

1.1 Type Tests

1.1 On the complete disc insulator with hardware Fittings

a) Power frequency voltages withstand test with corona control rings/grading ring and arcing horn under wet conditions

b) Switching surge voltage withstand test under wet condition

c) Impulse voltage withstand test under dry condition

d) Impulse voltage flashover test under dry condition

e) Voltage distribution test

f) Corona and RIV test under dry condition

g) Mechanical strength test

h) Vibration test

1.2 On disc Insulator

a) Verification of dimensions

b) Thermal mechanical performance test

c) Power frequency voltage withstand and flashover test (I) dry, (ii) wet

d) Impulse voltage withstand and flashover test (dry)

e) Visible Discharge test (dry)

f) RIV test (dry)

g) Residual strength test

h) Steep front test

2.0 **Acceptance tests**

2.1 For disc Insulators (Both porcelain and glass)

a) Visual examination

b) Verification of dimensions

c) Temperature cycle test

d) Galvanizing test

e) Mechanical performance test

f) Test on locking device for ball and socket coupling

g) Eccentricity test

h) Residual strength test

i) Metallurgical test

I) Grain size
ii) Inclusion rating
iii) Chemical analysis
iv) Microstructure

2 2 For porcelain insulators only

a) Electro-mechanical strength test
b) Puncture test
c) Porosity test

2 3 For glass insulators only

a) Thermal shock test
b) Steep wave front test/puncture test
c) Mechanical failing load test

3.0 **Routine tests**

3.1 For Disc Insulators

a) Visual Inspection
b) Mechanical routine test
c) Electrical routine test (for porcelain insulator only)
d) Thermal shock routine test (for glass Insulator only)

e) Polarised Light inspection (for glass insulator only)

4 0 Tests During Manufacture

On all components as applicable

a) Chemical analysis of Zinc used for galvanising
b) Chemical analysis, mechanical, metallorgaphic test and magnetic particle inspection for malleable castings.
c) Chemical analysis hardness tests and magnetic particle inspection for forging.
d) Hydraulic internal pressure tests on disc insulator shells

APPENDIX - F

Application guide

The design of a new line and the choice of insulators are a specialised task. Apart from the coordination of the line insulation to cope with lightning and switching impulses, the pollution severity of area must be known – through either direct measurement or experience.

Choice of creepage length

The recommended specific creepage lengths for ceramic insulators are given in *table1.* When using non-ceramic insulators, it is advisable to use a shortage creepage length, especially in location of severe pollution. Recent research indicates that under condition of severe humidity and dry band arcing, silicon rubber insulators may lose hydrophobicity. Until more conclusive results or revised specification are available, it is considered a safe approach to use IEC 815 for non-ceramic insulators as well.

Table 1

Site pollution Severity	low	medium	high	very high
Specific creepage Length (mm/kV)	16	20	25	>31

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